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Iron Ores of Northern Saskatchewan

by C. T. Harper

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Foreword

This report is published by the Saskatchewan Geological Survey as one of a series of reports resulting from a four-year program of geoscience surveys under the terms of the Canada-Saskatchewan Agreement on Mineral Exploration and Development in Northern Saskatchewan. This program was supported by funds provided by the Federal Departments of Energy, Mines and Resources (25 percent) and Regional Economic Expansion (25 percent), as well as by the Province of Saskatchewan (50 percent).

L.S. Beck
Director
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February, 1982.

Abstract

An integrated geological, geophysical and geochemical assessment of various types of iron occurrences was carried out in the Precambrian Shield area of northern Saskatchewan to determine whether there are any economically viable deposits. For the purposes of this study, an economically viable deposit had to be capable of supplying at least 100 million tonnes of ore grading at least 30 percent Fe, mineable by open pit methods, amenable to relatively simple concentrating procedures and readily accessible from existing and proposed transportation routes.

The iron occurrences investigated include metataconite (metamorphosed and extensively recrystallized) oxide facies sedimentary iron formation (Triana, VH, Ithingo Lake, Dot Lake, Fish Hook Bay and Spence Lake), sulphide facies iron formation and genetically related barren massive iron sulphide deposits (Nistoassini Lakes, Kirk Lake, Forbes Lake and Gossan Lake), deposits of plutonic association (Bassett Lake, Clearwater River and Olsen showing), significant aeromagnetic anomalies of uncertain cause (Kelic Lake and Popplewell Island), and residual deposits (bog iron ore and iron-cemented tills) which are closely associated with the iron sulphide deposits.

Superior-type banded quartz-magnetite/hematite metataconite deposits are most common in the Cree Lake Zone and less important in the Western Craton, with small Algoma-type oxide facies iron formations being present in the La Ronge Domain. Volcanogenic iron sulphide deposits are most common in the metavolcanic terrain of the La Ronge Domain and are smaller and less important in the Rottenstone, Glennie Lake and Flin Flon Domains. Some impressive but small residual bog iron occurrences accompany the sulphide deposits. Iron occurrences of plutonic association are not abundant in any region, but the best, Bassett Lake, is in a layered ultramafic intrusion in the La Ronge Domain.

Despite the relative abundance of metallic iron in northern Saskatchewan, none of the deposits appears to be economically viable at this time.

Keywords: Precambrian, northern Saskatchewan, iron deposits, sedimentary, volcanogenic, magmatic, residual, geology, geochemistry, genesis, economic evaluation

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Introduction

In 1974, the "Canada-Saskatchewan Subsidiary Agreement on Iron, Steel, and Other Related Metal Industries" was instituted in an attempt to stimulate steel production and related metal industries in Saskatchewan. The Interprovincial Steel and Pipe Corporation Limited (IPSCO), located in Regina, is wholly dependent upon scrap iron and steel for its raw materials. With scrap metal supplies decreasing and prices rising, a major objective of the agreement was to establish whether an economically viable iron ore body exists in Saskatchewan.

The Northern Iron Ore Exploration Project, of which this report is the summary, was designed to examine and evaluate iron ore deposits located in the Precambrian Shield of northern Saskatchewan. Only those deposits capable of supplying at least 100 million tonnes of ore grading at least 30 percent Fe, mineable by open pit methods, amenable to relatively simple concentrating procedures and readily accessible from existing and proposed transportation routes, would be considered economically viable.

The twelve areas examined between 1974 and 1976 included sedimentary iron formations, barren massive iron sulphide deposits, iron-bearing rocks of igneous affinity and aeromagnetic anomalies of unknown causes. Also included in the report are the results of investigations carried out on the Triana and VH deposits in 1973 by the Saskatchewan Department of Mineral Resources through its Mineral Evaluation Program (MEP) and on a previously unknown sedimentary iron formation occurrence near Spence Lake south of Wollaston Lake by W. Coombe.

History of Exploration

Iron occurrences, known in northern Saskatchewan since the turn of the century, were not of interest until the early 1920s. Sedimentary iron formations along the north shore of Lake Athabasca were investigated but not considered economic at that time. In 1956, Mawdsley (1960) examined a number of sedimentary iron formation occurrences in northwestern Saskatchewan and found them to be uneconomic. Two of the more promising deposits in the province, Triana at Black Lake (Assessment File 74P03-NW-0012)[1] and VH near Nyberg Lakes (Assessment File 74G04-NE-0018) were not discovered until 1949 and 1962 respectively. Only recently have they been considered as potential sources of iron.

In the mid-1950s, the largest iron deposits in Saskatchewan were found in the Choiceland - Kelsey Lake area in the east-central part of the province (Cheesman, 1964). Unfortunately, the deposits are covered by at least 600 m of Phanerozoic and glacial sediments, a factor which would considerably increase mining costs. Feasibility studies were undertaken by the provincial government on these deposits during the 1960s and they have been subjected to re-investigation under the terms of the Iron and Steel Agreement (East-Central Saskatchewan Iron Ore Project).

Physiography and Accessibility

Northern Saskatchewan is characterized by relatively low undulating terrain, relief generally being less than 30 m. In the southern part of the Shield,ridges composed of rock or glacial material rise 60 to 120 m above adjacent lakes. North of Lake Athabasca, particularly in the Beaverlodge-Tazin Lakes area, local relief of 90 to 120 m is common and, in a few places, reaches 200 m.

Much of northern Saskatchewan is covered by a thin veneer of glaciolacustrine clay, together with glacial tills and outwash sands and gravels. The area underlain by the Athabasca Group, as well as areas to the east and south, are overlain by extensive glacial deposits. The southern margin of the Shield is also an area of low relief and poor exposure characterized by vast tracts of muskeg and peat bog.

All of the areas examined are accessible by float- or ski-equipped aircraft from La Ronge, Buffalo Narrows or Uranium City.

Field Investigations

The selection of study areas was based on aeromagnetic anomalies and previously published information. Field investigations involved an integrated geological, geophysical and geochemical assessment, with trenching, diamond-drilling and detailed re-examination being undertaken when warranted. This work is summarized in Table 1. The data from the surveys were generally plotted at a scale of 1:4800, but larger scales of 1:2400 and 1:1200 were used where appropriate.

The ground magnetic surveys were initially carried out with a Geometrics G816 portable proton magnetometer. This instrument, with a 1.0 gamma resolution, is capable of measuring the total magnetic field from 30 000 to 90 000 gammas with a gradient tolerance of 500 gammas per metre. Because the proton magnetometer sensor is incapable of resolving the magnetic field in the

[1]Throughout this report, all such references are to reports in the Assessment Files, Saskatchewan Energy and Mines, Regina.

presence of high magnetic gradients, a portable Scintrex MFD-4 digital readout fluxgate magnetometer was used after 1974. This instrument, which measures the vertical component of the earth's magnetic field, has a 1.0 gamma resolution when operated on a tripod and a 10 gamma resolution when hand held. It has a range of 200 000 gammas.

Grab, composite chip, channel and core samples, as well as overburden soil samples, were collected and analyzed by various laboratories (see Table 1). Grab samples of bedrock were collected for assay and other chemical analyses, and to provide a reference collection. Composite chip samples were collected for assay purposes from trenches. Several rock chips were taken at regular intervals (0.15, 0.30 and 0.60 m) along the trench and bagged every 1.5 or 3.0 m. Channel samples were collected for assay purposes, generally at 0.3 m intervals. Mineralized sections from drill core were split and half of the core assayed. Soil samples from the B horizon were collected wherever a true soil profile was developed.

Trenches were excavated at Ithingo and Nistoassini Lakes in 1974 and at Forbes Lake in 1975. The work was contracted out to the Prospectors Incentive Plan (PIP) operated by the Department of Northern Saskatchewan.

Diamond-drilling, contracted to PIP, was undertaken at Bassett and Forbes Lakes during the period January through March, 1976. Two vertical holes totalling 155.4 m were drilled from the surface of a small lake about 1 km southeast of Bassett Lake, and five inclined holes totalling 808.6 m were drilled along the length of the iron sulphide zones at the northeast end of Forbes Lake.

The core was shipped to La Ronge for logging, splitting and sampling, and then sent out for analytical and petrographic studies. Because of storage problems at La Ronge, 15 cm long samples were taken from each core box and where major lithological changes occurred. Mineralized sections were kept intact.

Acknowledgments

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To the companies who held mineral properties at the time of investigation, I extend my gratitude for their cooperation.

Lastly, I am grateful to the following people for their very capable assistance in the field: L. Allen, R. Shirkie and J. Adair in 1974; J. Evanochko, P. Stokes and B. Campbell in 1975; and G. Billingsley, K. Jordan, B. Campbell and G. Chappell in 1976.

Table 1. Summary of Field Investigations by Study Area

Name and Location	*Year*	*Geologist; Mapping Scale*	*Ground Mag Survey: Type & Scale*	*Geochemical Samples[1]: Type and Number*		*Number of Trenches*	*Diamond Drilling: No. of Holes and Total Length*	*Line Cutting*	*Elem Deter*
Triana 74P-4-NW	1973	Langenburg; 1:2400	Proton 1:2400	Chip	434			40.47 km	Tota
VH 74G-2-NE	1973	Langenburg; 1:2400	Proton 1:2400	Chip	32			77.928 km	Tota
Ithingo Lake 74B-11-SE	1974	Harper;	Proton						Acid Mn,
West		1:2400	1:2400	Composite Chip	12				
East		1:4800	1:4800			3		6.0 km	
Nistoassini Lakes 64D-4-N & 64D-5-S	1974	Harper & Allen; 1:1200 1:2400 1:4800	Proton 1:4800	Composite Chip Grab	141 52	8		0.968 km	Fe, C
	1976	Harper; 1:12 000 Billingsley; 1:4800	MFD-4 1:2400	Grab Soil	27 483			1.5 km	*Grab* *majo* *Soil:* Fe, C
Kirk Lake[2] 74A-1-NE	1974	Harper & Allen; 1:4800		Composite Chip	12				Fe
Forbes Lake 73P-15-SE & NE	1975	Harper; 1:2400 1:4800	MFD-4 1:2400 1:4800	Grab Composite Chip Soil Drill Core	10 99 579 45	13	5 inclined 808.6 m	1.2 km	*Grab* Fe, Ag, *Com* *Soil:* Fe, C *Core* Cu, C
Dot Lake 74B-6-SE	1975	Harper; 1:2400	MFD-4 1:2400	Grab	19			2.43 km	Acid Al, C S, P,
Olsen 74A-13-SW	1975	Harper; Reconnaissance							
Clearwater River 74F-2-NE	1975	Harper; Reconnaissance	MFD-4	Grab	3				Acid Mg,
Kelic Lake 74F-8-NW	1975	Evanochko; Reconnaissance	MFD-4 Reconnaissance						
Popplewell Island 74C-8-NE	1975	Harper; Reconnaissance	MFD-4 Reconnaissance						
Gossan Lake[2] 73P-13-SE	1975	Harper; Reconnaissance & 1:1200	MFD-4 Reconnaissance & 1:1200	Grab	19				Al, C Si, S Acid Fe, C
Bassett Lake 73P-10-SW	1975	Harper; Reconnaissance	MFD-4 1:4800	Grab Composite Chip Drill Core	1 9 40		2 vertical 155.4 m		*Grab* *Chip:* *Core:* Al, M acid Cu, C
Fish Hook Bay, Lake Athabasca 74N-8-NW	1976	Harper & Billingsley; Reconnaissance		Grab Channel	1 350				Acid Also major every
Spence Lake 64E-12-SE	1978	Coombe; 1:4800		Grab	14				Whol oxide

[1]Analyses by: University of Regina (1973-1976)
Bondar-Clegg and Company Limited, Vancouver (1974-75)

[2]Unofficial lake name

estigations by Study Area

Geologist; Mapping Scale	Ground Mag Survey: Type & Scale	Geochemical Samples[1]: Type and Number		Number of Trenches	Diamond Drilling: No. of Holes and Total Length	Line Cutting	Elements Determined	Thin or Polished Sections (no. of each)
Langenburg; 1:2400	Proton 1:2400	Chip	434			40.47 km	Total Fe	
Langenburg; 1:2400	Proton 1:2400	Chip	32			77.928 km	Total Fe	
Harper;	Proton						Acid soluble Fe, Si Mn, Mg, P, S, Ti	P.S. (1)
1:2400	1:2400	Composite Chip	12					
1:4800	1:4800			3		6.0 km		
Harper & Allen;	Proton	Composite Chip	141	8		0.968 km	Fe, C	T.S. (4)
1:1200	1:4800	Grab	52					P.S. (14)
1:2400								
1:4800								
Harper;	MFD-4	Grab	27			1.5 km	*Grab:* Whole rock	T.S. (93)
1:12 000	1:2400	Soil	483				major oxides	
Billingsley; 1:4800							*Soil:* Acid soluble Fe, Cu, Zn, Pb	
Harper & Allen; 1:4800		Composite Chip	12				Fe	T.S. (1)
Harper;	MFD-4	Grab	10	13	5 inclined	1.2 km	*Grab:* Acid soluble	T.S. (15)
1:2400	1:2400	Composite Chip	99		808.6 m		Fe, Mn, Mg, Ti, Au,	P.S. (17)
1:4800	1:4800	Soil	579				Ag, Cu, Zn	
		Drill Core	45				*Composite Chip* & *Soil:* Acid soluble Fe, Cu, Zn	
							Core: Acid soluble Fe Cu, C, Zn, Ni, Au	
Harper; 1:2400	MFD-4 1:2400	Grab	19			2.43 km	Acid soluble Fe, Si, Al, Ca, Mg, Mn, Ti, S, P, Ni	
Harper; Reconnaissance								P.S. (1)
Harper; Reconnaissance	MFD-4	Grab	3				Acid soluble Fe, Mg, Mn, Ti	
Evanochko; Reconnaissance	MFD-4 Reconnaissance							
Harper; Reconnaissance	MFD-4 Reconnaissance							
Harper; Reconnaissance & 1:1200	MFD-4 Reconnaissance & 1:1200	Grab	19				Al, Ca, Mg, Mn, Ti, Si, S Acid soluble Fe, Cu, Ni, Zn	
Harper; Reconnaissance	MFD-4 1:4800	Grab	1		2 vertical		*Grab & Composite Chip:* Fe, Cu, Ni	T.S. (11)
		Composite Chip	9		155.4 m		*Core:* Fe, Ti, Ca,	
		Drill Core	40				Al, Mg, Mn, Si, P, S; acid soluble Fe, Ti, Cu, Cr, Ni	
Harper & Billingsley; Reconnaissance		Grab	1				Acid soluble Fe, Au	T.S. (10)
		Channel	350				Also whole rock major oxides on every 10th	P.S. (6)
Coombe; 1:4800		Grab	14				Whole rock major oxides, S	

lna (1973-1976)
d Company Limited, Vancouver (1974-75)

General Geology of the Iron Deposits

Geological Setting of Northern Saskatchewan

The Precambrian rocks of northern Saskatchewan form part of the Churchill Structural Province of the Canadian Shield. Several large areas of lithologic and structural uniformity (lithostructural domains) have been recognized (Lewry and Sibbald, 1977) in the Saskatchewan portion of the Shield (Figure 1). North of Lake Athabasca, the Shield has been divided into various linear belts and stable blocks (Beck, 1969) which have been incorporated into the domain classification.

For further information on the geology, structure and history of the Shield in Saskatchewan, the reader is referred to the Geological Map of Saskatchewan (Macdonald and Broughton, 1980) and papers by Lewry and Sibbald (1977) and Lewry et al. (1978).

Classification of Iron Occurrences

The classification of iron deposits[1] in northern Saskatchewan follows that of Gross (1959, 1965) and is summarized in Table 2. Most deposits belong to Types E and F of Group II iron formations. Type E metataconite or itabirite deposits include "metamorphosed iron-formations that have undergone extensive recrystallization", while Type F are "pyrite-rich iron-formations of potential ore value" (Gross, 1965, p.50). Commonly associated with and genetically related to the Type F deposits are barren, massive, iron sulphide deposits; however, some of these may belong to Type D, Group V and include skarn, contact metasomatic, vein, and structurally controlled emplacements of iron minerals. For convenience, these are described with the iron sulphide iron formations. Post-Pleistocene bog iron deposits, some still forming in low-lying swampy areas, are also spatially related to the pyrite-rich iron formations and barren massive sulphides.

Group IV deposits, those directly associated with plutonic rocks, are divided into Type A (mafic and ultramafic association) and Type C (acid, intermediate or alkalic associations). Although the Bassett Lake occurrence is obviously a magmatic deposit (Table 2), the origin of the Clearwater River and Olsen occurrences is not so obvious. However, since their host rocks are granite and pegmatite, they have been included with the magmatic deposits.

The Kelic Lake and Popplewell Island occurrences, represented only by aeromagnetic anomalies and no surface exposure, are difficult to classify and are listed under "Other Occurrences". However, on the basis of the spatial relationship to both regional geology and regional aeromagnetic patterns, the Kelic Lake anomaly appears similar to the Clearwater River occurrence, whereas the Popplewell Island anomaly may be another metataconite deposit.

[1]In this report, deposit is not used in the economic sense.

Table 2. Classification of Iron Occurrences in Northern Saskatchewan

Group	Classification	Occurrences[1]
II	Iron Formations	
	Type E: Metataconite or Itabirite	Triana (1), VH (2), Ithingo Lake (3), Dot Lake (4), Fish Hook Bay (5), Spence Lake (6)
	Type F: Pyrite-rich iron formation (and associated massive sulphide deposits)	Nistoassini Lakes (7), Kirk Lake (8), Forbes Lake (9), Gossan Lake (10)
III	Residual Deposits, Chemically and Mechanically Transported Surface Deposits	Same localities as Type F, Group II
	Type D: Bog iron deposits	
IV	Deposits Directly Associated with Plutonic Rocks	
	Type A: Associated with basic and ultrabasic rocks	Bassett Lake (11)
	Type C: Associated with acid, intermediate or alkalic rocks	? Clearwater River (12), Olsen (13)
V	Skarn, Contact Metasomatic and Structurally Controlled Emplacement Deposits	
	Type D: Massive and disseminated iron sulphide deposits	May occur in same localities as Type F Group II
	Other Occurrences; Aeromagnetic Anomalies	Kelic Lake (14), Popplewell Island (15)

[1]Numbers in brackets refer to locations shown on Figure 1

Distribution of Iron Occurrences

Iron deposits occur in most lithostructural domains (Figure 1). Metataconite deposits, which include banded quartz-magnetite and quartz-hematite iron formations, are concentrated in the Mudjatik Domain, whereas the iron sulphide facies iron formations and barren massive sulphide deposits are restricted to the La Ronge Domain. A brief discussion of the distribution of iron occurrences by domain follows.

Western Granulite Domain

Several iron sulphide (pyrite-pyrrhotite) and iron oxide (magnetite) occurrences in the Western

Granulite Domain are weakly disseminated and are therefore not shown in Figure 1. Magnetite concentrations of about 10 percent in granitic rocks are responsible for the aeromagnetic anomaly of the Clearwater River occurrence. Iron oxide and iron silicate facies metataconite occur in basement rocks which form the core of the circular Carswell Structure (Harper, 1977), but the occurrences are not economically significant.

Virgin River and Mudjatik Domains

These two domains contain most of the metataconite iron formations in northern Saskatchewan. In the Virgin River Domain, iron sulphides are associated with graphitic pelites of the Virgin Schist Group (Johnson, 1968; Wallis, 1970), and significant iron oxide iron formation has been reported from two localities (the VH and Triana deposits).

Metataconite deposits are dominant in the Mudjatik Domain. They have pronounced aeromagnetic expressions, some greater than 30 km in length, and occur within narrow bands of supracrustal rocks. The deposits are mainly banded quartz-magnetite iron formation and many are accompanied by minerals typical of silicate, sulphide and carbonate facies iron formations. Iron sulphides in graphitic pelites and magnetite in mafic to ultramafic rocks are present in these domains but do not constitute important iron occurrences. The eastern limit of metataconite deposits more or less corresponds to the Mudjatik-Wollaston domain boundary.

Wollaston Domain

Iron occurrences, rare in the Wollaston Domain, are chiefly confined to disseminated pyrite in graphitic pelites and in quartzites associated with lead-zinc mineralization, such as Sito Lake, Fable Lake and George Lake (Harper, 1975a). Coarse crystalline magnetite, up to a few percent (by volume), is associated with pink pegmatite. A titaniferous hematite deposit, the Olsen occurrence, is the only substantial deposit related to a pegmatitic host. A small occurrence of lean (less than 15 percent Fe) oxide facies iron formation was reported from the northeast end of Wollaston Lake (Chandler, 1978). The recent recognition of laterally persistent oxide and silicate facies iron formation about 32 km south of Wollaston Lake (Coombe, 1978) suggests that sedimentary iron formation, perhaps mostly silicate facies, may be more common in the Wollaston Domain than previously thought.

Rottenstone Domain

The iron occurrences of this domain consist essentially of disseminated to massive pyrite and pyrrhotite, occurring in long narrow zones of highly metamorphosed sedimentary rocks surrounded by uniform migmatites and felsic gneisses. One notable occurrence of pyrrhotite-pyrite mineralization, accompanied by nickel, copper, platinum and palladium, occurs in a pyroxenite host at the defunct Rottenstone Lake Mine (Beck, 1959). Small occurrences of bog iron ore are commonly associated with the sulphide mineralization.

La Ronge Domain

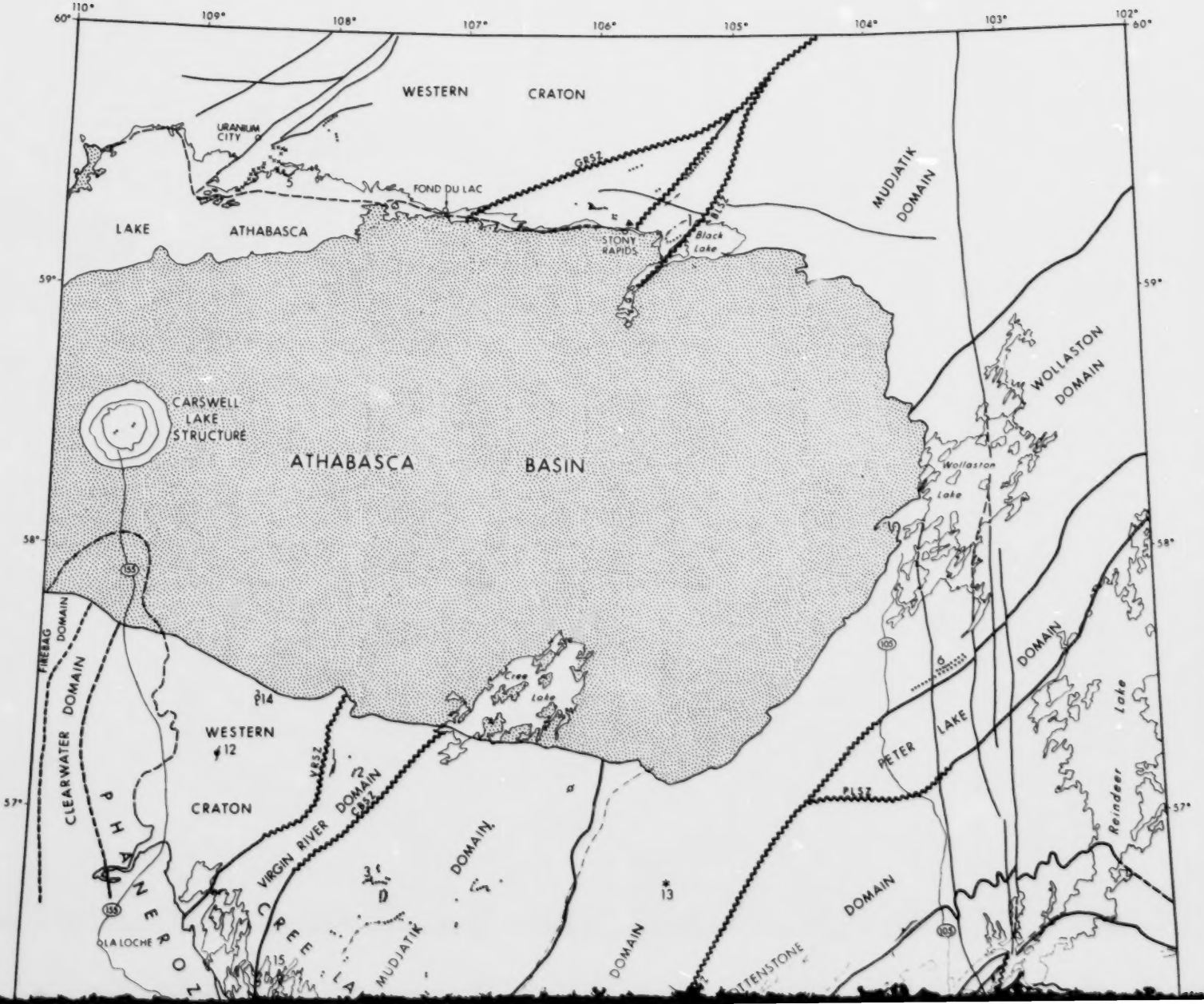
The La Ronge Domain is noted for its numerous barren massive sulphide deposits associated with both volcanic and sedimentary rocks. Exhalative sulphide facies iron formations are also abundant and appear to have been deposited in both distal and proximal environments. Oxide facies iron formations in the La Ronge Domain are rare and usually occur as thin discontinuous bands. Group IV (plutonic type) deposits, normally associated with gabbros, are present (e.g. Bassett Lake) but not important. Bog iron ores, which typically occur in close proximity to the iron sulphide occurrences, are abundant but unimportant in the La Ronge Domain.

Lake Athabasca Region

Ferruginous quartzites and dolomites, and iron oxide iron formation are present in the Beaverlodge area. North of Fond du Lac River, thin zones of oxide iron formation are interlayered with metavolcanic rocks, while disseminated magnetite is associated with noritic rocks.

Geochemistry

Table 3 presents the average chemical composition of selected Canadian iron deposits chosen for their similarity to the occurrences found in northern Saskatchewan. Acceptable impurity levels for various grades of iron ore are also given.


110°
109°
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59°
58°
57°
WESTERN CRATON
URANIUM CITY
FOND DU LAC
LAKE ATHABASCA
STONY RAPIDS
Black Lake
MUDJATIK DOMAIN
WOLLASTON DOMAIN
CARSWELL LAKE STRUCTURE
ATHABASCA BASIN
Wollaston Lake
FIREBAG DOMAIN
CLEARWATER DOMAIN
WESTERN CRATON
VIRGIN RIVER DOMAIN
MUDJATIK DOMAIN
PETER LAKE DOMAIN
Reindeer Lake
LA LOCHE
DOMAIN
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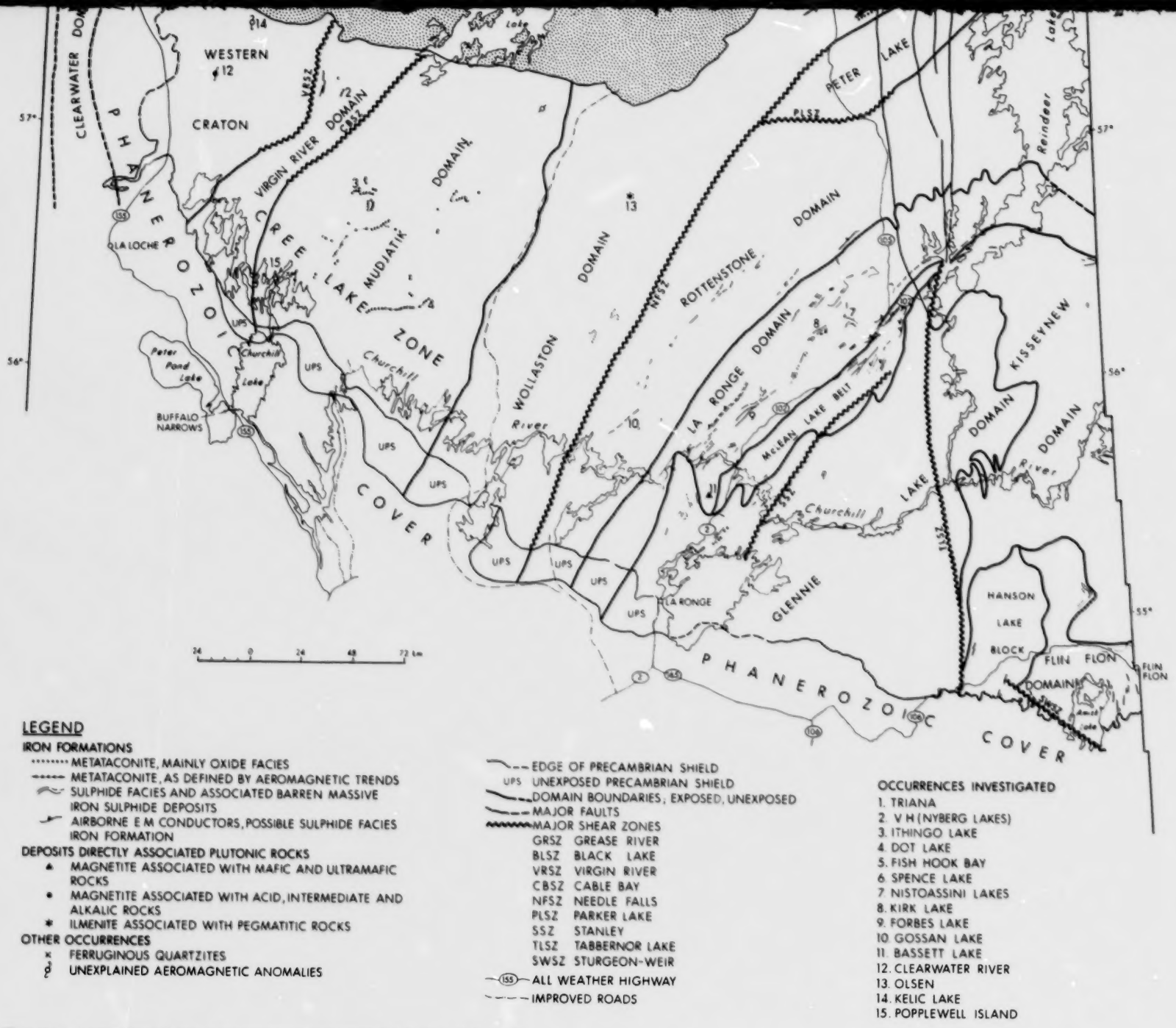
P14
P12
P15
P13
155
165
103



LEGEND

IRON FORMATIONS
- ····· METATACONITE, MAINLY OXIDE FACIES
- ----- METATACONITE, AS DEFINED BY AEROMAGNETIC TRENDS
- SULPHIDE FACIES AND ASSOCIATED BARREN MASSIVE IRON SULPHIDE DEPOSITS
- AIRBORNE E M CONDUCTORS, POSSIBLE SULPHIDE FACIES IRON FORMATION

DEPOSITS DIRECTLY ASSOCIATED PLUTONIC ROCKS
- ▲ MAGNETITE ASSOCIATED WITH MAFIC AND ULTRAMAFIC ROCKS
- • MAGNETITE ASSOCIATED WITH ACID, INTERMEDIATE AND ALKALIC ROCKS
- * ILMENITE ASSOCIATED WITH PEGMATITIC ROCKS

OTHER OCCURRENCES
- × FERRUGINOUS QUARTZITES
- UNEXPLAINED AEROMAGNETIC ANOMALIES

- EDGE OF PRECAMBRIAN SHIELD
- UPS UNEXPOSED PRECAMBRIAN SHIELD
- DOMAIN BOUNDARIES, EXPOSED, UNEXPOSED
- MAJOR FAULTS
- MAJOR SHEAR ZONES
  - GRSZ GREASE RIVER
  - BLSZ BLACK LAKE
  - VRSZ VIRGIN RIVER
  - CBSZ CABLE BAY
  - NFSZ NEEDLE FALLS
  - PLSZ PARKER LAKE
  - SSZ STANLEY
  - TLSZ TABBERNOR LAKE
  - SWSZ STURGEON-WEIR
- (155) ALL WEATHER HIGHWAY
- IMPROVED ROADS

OCCURRENCES INVESTIGATED
1. TRIANA
2. V H (NYBERG LAKES)
3. ITHINGO LAKE
4. DOT LAKE
5. FISH HOOK BAY
6. SPENCE LAKE
7. NISTOASSINI LAKES
8. KIRK LAKE
9. FORBES LAKE
10. GOSSAN LAKE
11. BASSETT LAKE
12. CLEARWATER RIVER
13. OLSEN
14. KELIC LAKE
15. POPPLEWELL ISLAND

Figure 1. *Locations of iron occurrences investigated during this study.*

Table 3. Average Chemical Composition of Some Iron Formations and Iron Ores. All Values in Weight Percent

Ore Type	*SiO_2*	*Al_2O_3*	*MgO*	*CaO*	*Acceptable Impurity Levels*	*P*	*S*	*Mn*
Bessemer[5]	11	0.5 to 3, but up to 8.5	Both CaO & MgO are acceptable, as they are self-fluxing		Moisture content should be 10%	0.045	0.1	0.5
Low P Non-Bessemer[5]	11					0.180	0.1	2 to
High P Non-Bessemer[5]	11					0.180	0.1	5
Manganiferous[5]	11					0.180	0.1	8

	SiO_2	*Al_2O_3*	*Fe_2O_3*	*FeO*	*MgO*	*CaO*	*Na_2O*	*K_2O*	*H_2O^+*	*H_2O^-*	*CO_2*	*P_2O_5*	*S*	*Mn*
Algoma Type:[6] Oxide (Moose Mountain)	45.20	0.25			1.59	1.06								0.24
Superior Type:[6]														
Average Gunflint	60.51	1.20			0.52	0.67			tr[1]	tr[1]		0.05	0.59	
Average Labrador	48.50	0.79	41.60	5.46	0.60	0.01	0.03	0.01	2.46	0.09	0.06	0.04	0.01	0.1
Average Mesabi Range	51.12	1.31	10.81	23.86	3.26	0.75	tr[1]	tr[1]	Tot[2] H_2O = 3.43			0.04		4.77
Iron Formation Facies:[7]														
Average Oxide Facies	44.208	0.883	38.245	8.635	2.105	1.288			Tot[2] H_2O = 1.455		3.26	0.385		0.20
Average Carbonate Facies	34.58	1.09	1.845	31.720	3.126	1.162	0.04	0.20	Tot[2] H_2O = 0.876		22.96	0.512	0.05	1.37
Average Silicate Facies	51.302	2.833	7.142	24.805	3.760	0.535	1.180	2.090	0.442	3.960	4.906	0.490		2.08
Average Sulphide Facies	36.670	6.90		2.350	0.650	0.130	0.260	1.810	0.55	1.25		0.200		0.00
Knob Lake Ores:[8]												*(%P)*		*(%Mn*
Bessemer Concentrate	6.29	0.96	Sol[3]	Fe = 55.5	0.02	0.13			Tot[2] H_2O = 8.96			0.33	0.007	0.39
Non-Bessemer Concentrate	6.05	1.24	Sol[3]	Fe = 52.7	0.02	0.15			Tot[2] H_2O = 10.57			0.081	0.005	1.08
Magniferous Concentrate	6.69	1.52	Sol[3]	Fe = 46.9	0.02	0.12			Tot[2] H_2O = 10.68			0.118	0.005	5.26
Average Appalachian Residual Deposit:[9]	8.67	3.245			0.47	0.57			Volatiles = 18.77		0.094	0.025	1.41	
Deposits Associated with Basic Plutonic Rocks:[10]								*Cu*	*V*	*Ni*	*Co*			
Allard Lake Core								0.092	0.21	0.02	0.015	0.009	0.535	0.09
								Cu	*V_2O_5*	*Ni*	*Cr_2O_3*			
Typical Ore	3.7	3.1	26.2	28.3	3.2	0.8	0.30	0.02	0.30	0.03	0.10	0.015	0.28	0.17
Average Titaniferous Magnetite Deposits:[11]							*V*							
Phosphorus-poor	7.59	6.14			7.31	0.185	0.232					0.031	0.05	
Phosphatic	5.97	5.83			5.30	8.58	0.098					2.89	0.08	

[1]tr = trace
[2]Tot = Total
[3]Sol = Soluble
[4]LOI = Loss-on-ignition

References:

[5]Gross, 1965, p.67-70
[6]*ibid.*, Table X, p.96-97
[7]*ibid.*, Table VIII, p.85
[8]Gross, 1968, Table VIII, p.44
[9]Gross, 1967, Table V, p.29
[10]*ibid.*, Table VIII, p.60
[11]*ibid.*, Table X, p.68

mposition of Some Iron Formations and Iron Ores. All Values in Weight Percent

							Acceptable Impurity Levels								
Al_2O_3			MgO	CaO						P	S	Mn	Ti	Others	
0.5 to 3, but up to 8.5			Both CaO & MgO are acceptable, as they are self-fluxing				Moisture content should be 10%			0.045	0.1	0.5	0.1	Cu, Pb, Zn, A, V, Cr & Ni: combined total should be 0.05%	
										0.180	0.1	2 to	0.1		
										0.180	0.1	5	0.1		
										0.180	0.1	8	0.1		
Al_2O_3	Fe_2O_3	FeO	MgO	CaO	Na_2O	K_2O	H_2O^+	H_2O^-	CO_2	P_2O_5	S	MnO	TiO_2	C	FeS_2	Total Fe
0.25			1.59	1.06								0.24				36.70
1.20			0.52	0.67			tr[1]	tr[1]		0.05	0.59					25.22
0.79	41.60	5.46	0.60	0.01	0.03	0.01	2.46	0.09	0.06	0.04	0.01	0.11		0.07		29.14
1.31	10.81	23.86	3.26	0.75	tr[1]	tr[1]	Tot[2] H_2O = 3.43			0.04		4.77				26.11
0.883	38.245	8.635	2.105	1.288			Tot[2] H_2O = 1.455		3.26	0.385		0.20		0.060		
1.09	1.845	31.720	3.126	1.162	0.04	0.20	Tot[2] H_2O = 0.876		22.96	0.512	0.05	1.371	0.072	1.880		26.57
2.833	7.142	24.805	3.760	0.535	1.180	2.090	0.442	3.960	4.906	0.490		2.08	0.52	0.21		18.302
6.90		2.350	0.650	0.130	0.260	1.810	0.55	1.25		0.200 (%P)		0.002 (%Mn)	0.39	7.28	38.70	
0.96	So1[3] Fe=55.5		0.02	0.13			Tot[2] H_2O = 8.96			0.33	0.007	0.39		LOI[4] =	4.03	
1.24	So1[3] Fe=52.7		0.02	0.15			Tot[2] H_2O = 10.57			0.081	0.005	1.08		LOI[4] =	5.12	
1.52	So1[3] Fe=46.9		0.02	0.12			Tot[2] H_2O = 10.68			0.118	0.005	5.26		LOI[4] =	5.97	
3.245			0.47	0.57			Volatiles = 18.77		0.094	0.025	1.41				52.17	
						Cu	V	Ni	Co							
						0.092	0.21	0.02	0.015	0.009	0.535	0.09	34.825			40.45
						Cu	V_2O_5	Ni	Cr_2O_3							
3.1	26.2	28.3	3.2	0.8	0.30	0.02	0.30	0.03	0.10	0.015	0.28	0.17	35.0			40.2
					V											
6.14			7.31	0.185	0.232					0.031	0.05		16.44			46.0
5.83			5.30	8.58	0.098					2.89	0.08		15.24			37.34

Iron Formation Type

Triana

Iron was discovered in the Black Lake area in 1949 (Assessment File 73P03-NW-0012), on the TR concession of Nisto Mines Limited. In 1956, Triana Exploration Limited began detailed investigations of the magnetic anomalies on the Fer, Mag, Hem and Net claim groups, and on the Jim claim group optioned from Nisto Mines. The company outlined a zone of iron mineralization at least 6600 m long and averaging 60 m in width, with local widths of 120 to 150 m (Figure 2). Detailed sampling of sections of the iron formation indicated potential reserves of 1 200 000 to 1 500 000 tonnes per vertical metre (400,000 to 500,000 tons per vertical foot) grading 30 to 40 percent Fe (Beck, 1959; Assessment File 74P03-NW-0001). Claims covering the occurrence were subsequently allowed to lapse. The property was restaked in 1970, but no work was submitted and claims again lapsed in 1973 (Pearson, 1973). In 1973, claim block CBS 1808 and the Twig group of nine claims were staked on behalf of the province. As part of the MEP study carried out during 1973, Langenburg (1973) and LaBine (1973) conducted detailed geological and ground magnetic surveys, respectively, on the main deposit near Isics Lake. In addition, samples were taken on four traverses across the iron formation. The geological setting of the Triana deposit and a generalized stratigraphy are shown in Figure 2. The MEP study indicated that, due to dilution by interlayered metasediments and diabase dykes and sills, the deposit was much smaller than indicated by the earlier work, averaging only 113 000 tonnes per vertical metre (38,000 tons per vertical foot), for a total of 17 000 000 tonnes (19,000,000 tons) grading 30 to 35 percent Fe (Pearson, 1973). The claims were subsequently allowed to lapse. The area is presently included in an exploration permit held by Saskatchewan Mining Development Corporation.

General Geology

The northeasterly trending, westerly dipping Black Lake Shear Zone, which forms an escarpment along the western shore of Black Lake (Gilboy, 1978), separates flat-lying Athabasca Group sediments to the east from the older gneisses and granitic rocks to the west. The Triana deposit lies about 1.6 km west of the fault (Figure 2) in an area characterized by generally easterly trending, steeply northwest to vertically dipping, amphibolite grade metasediments of the Hybrid Gneiss Complex (Johnston, 1963; Gilboy, 1978), believed to belong to the Tazin Series

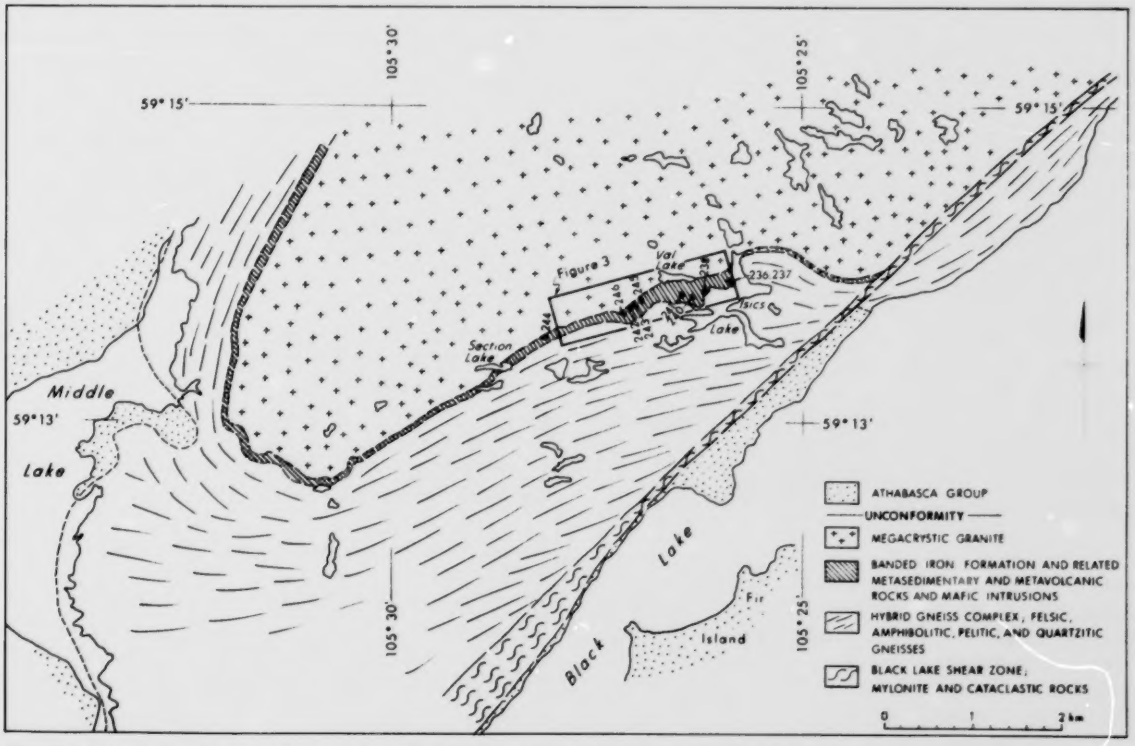


Figure 2. *Geologic setting of the Triana iron deposit. Solid dots give locations of samples listed in Table 3. Compiled from assessment work data submitted by Triana Exploration Limited and geologic mapping by Gilboy (1978).*

(Beck, 1959; Assessment File 74P03-NW-0001). The rocks consist of amphibole and biotite-amphibole gneisses, quartzites, metapelites and banded quartz-hematite-magnetite iron formation, which have been intruded by amphibolites, megacrystic granite gneiss and numerous diabase dykes and sills (Langenburg, 1973; Assessment File 74P03-NW-0001).

At least two periods of deformation produced the thickened sections of iron formation observed at Isics and Section Lakes (Figure 2). Regional metamorphism reached middle to upper amphibolite facies. Granulite facies conditions are reported in the vicinity of the Triana occurrence (Colborne, 1961; Johnston, 1963, 1964; Langenburg, 1973). Subsequent brittle deformation, some of which postdates the deposition of the Athabasca Group sediments, produced mylonite zones in which the high grade metamorphic rocks were retrogressed to greenschist facies.

Rock Descriptions

The rock units recognized by Langenburg (1973) at Triana and their distribution in the vicinity of Isics Lake are shown in Figure 3. The following rock descriptions are largely paraphrased from Langenburg's work, with additional information from Gilboy (1978) and Assessment File 74P03-NW-0001.

Outcrops of **iron formation** typically have a blue-grey metallic colour caused by both specular hematite and magnetite. Specularite and magnetite are the most abundant iron oxides, with hematite becoming more abundant, and magnetite less abundant, toward the west. The iron formation is generally well layered, with bands less than 1.0 cm thick consisting of white to grey quartz, commonly with garnet, green amphibole and biotite. These bands alternate with quartzose bands of comparable thickness containing fine- to medium-grained specularite and magnetite. Brick red earthy hematite commonly fills networks of tiny fractures within the specularite. Fine-grained specularite also occurs as minute veinlets subparallel to bedding and cutting the late diabase intrusives (Assessment File 74P03-NW-0001). The iron formation is commonly interlayered with metasediments that vary from a centimetre or so to 14 m in thickness.

The banding and mineralogy of the iron formation suggests original precipitation as a cherty iron oxide iron formation that may be in part transitional to the iron silicate facies. This is supported by the presence of iron silicate minerals (garnet, amphibole, biotite) in the quartz-rich layers.

Mixed paragneiss, generally in contact with the iron formation, is composed of quartzites (some of them garnetiferous), biotite gneisses and biotitic amphibolites. These rocks commonly weather brown and possess a well-developed foliation parallel to the lithologic layering.

Amphibolite of uncertain origin has a well-developed layering due to alternating thin bands of quartz-feldspar and amphibole. The amphibole has a strong preferred orientation. Local migmatization has occurred.

(Amphibole-garnet) biotite gneiss is essentially a quartzofeldspathic rock with variable amounts of mafic minerals. It is composed of white to grey biotite gneisses, greenish-grey amphibole-biotite gneisses, white meta-arkoses and transitional varieties. Pegmatitic mobilizate is common in parts of the rock.

(Garnet) amphibolite consists of dark green, fine- to medium-grained, massive to weakly foliated, irregularly shaped amphibolite masses of known igneous origin. These intrude the mixed paragneisses discordantly and are in turn intruded by the granite/megacrystic granite and metadiabase/metagabbro intrusive suites. The major mineral phases are amphibole, feldspar, quartz and occasionally garnet.

All of the above rock units are truncated to the north by a large mass of pink **granite and megacrystic granite**. The granite is massive to foliated and consists mainly of quartz, feldspar and biotite. Foliated varieties, characterized by elongate pink and white feldspar megacrysts, are contained in a weakly schistose biotite-quartz feldspar matrix. Several smaller granitic bodies intrude the metasediments south of the main body. These, in turn, are intruded by the metadiabase and metagabbro.

The large granite body extends northeastward, parallel to the Black Lake Shear Zone, for a distance of 32 km (Johnston, 1963, 1964). This granite is thought by Lewry and Sibbbald (1977) to be similar to the Wasekamio Junction granite; both have been emplaced along major structural breaks, in this case the Black Lake Shear Zone.

Dykes and sills of **metadiabase and metagabbro** intrude all the above rock units. They are characteristically dark green in colour, weather brown and vary considerably in grain size and texture. Some of the magnetic highs in the iron formation and elsewhere are caused by these basic intrusions.

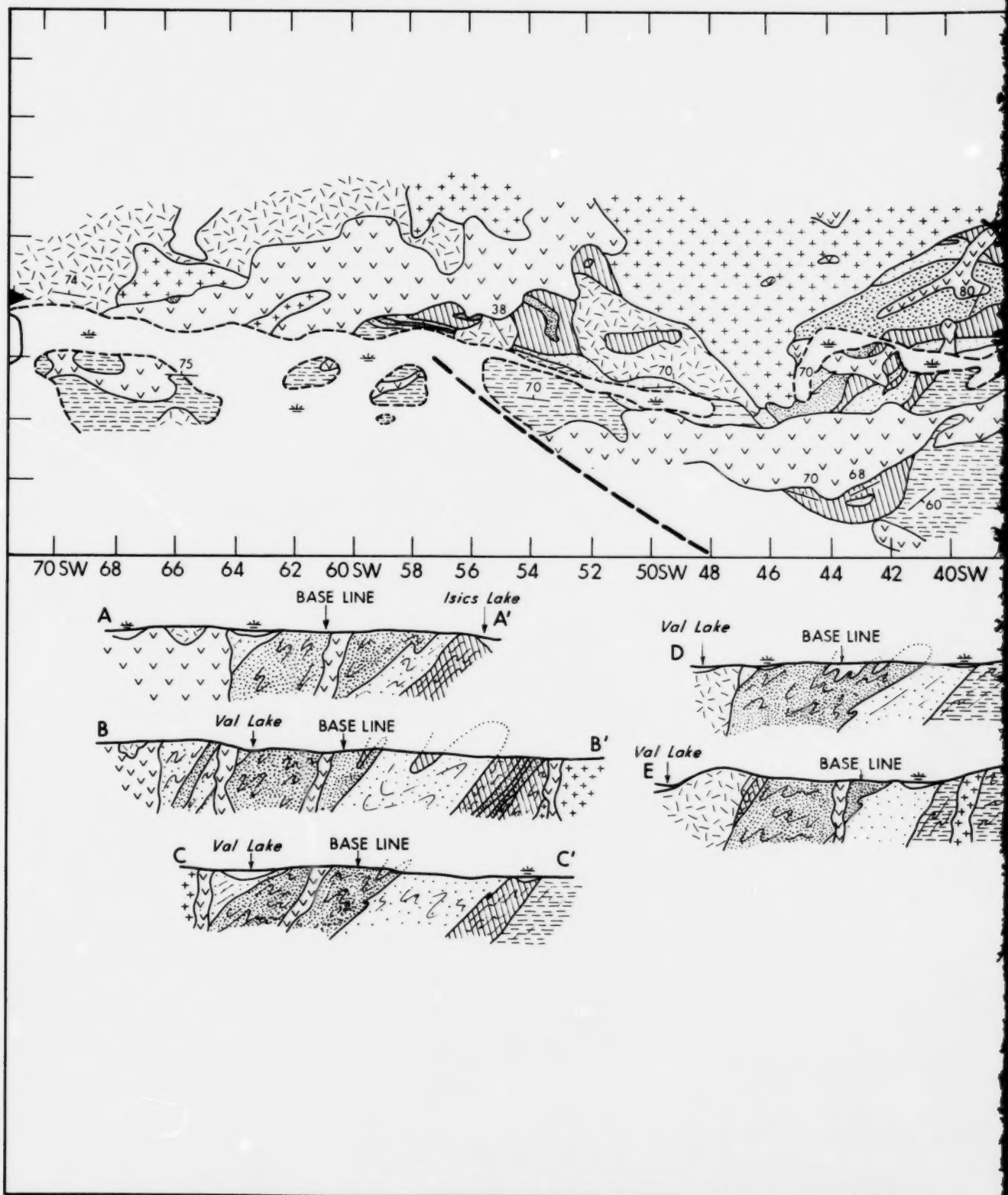


Figure 3. *Geology and cross-sections of the Triana iron deposit in the vicinity of Isics Lake (modified from Langenberg, 1973).*

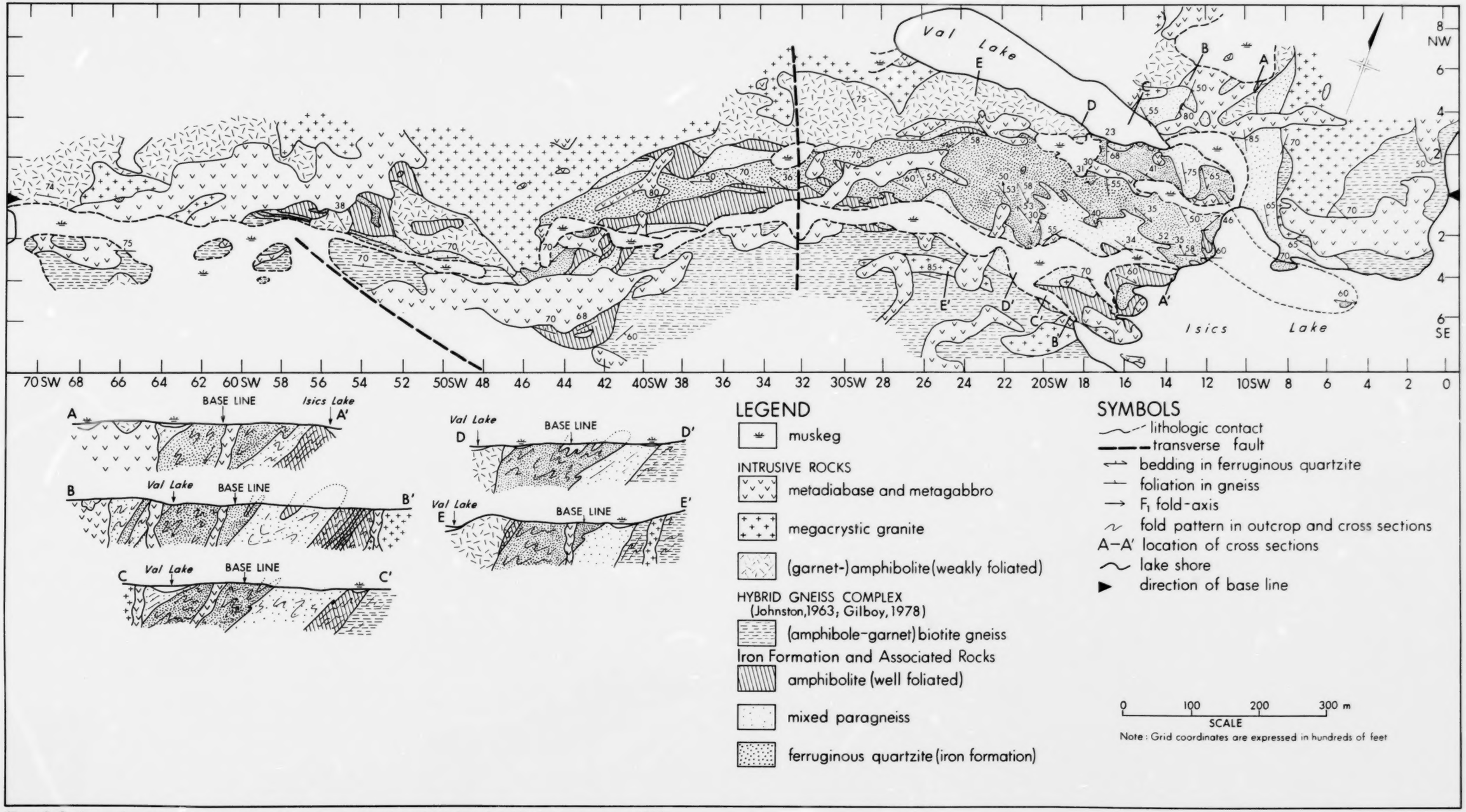


Figure 3. *Geology and cross-sections of the Triana iron deposit in the vicinity of Isics Lake (modified from Langenberg, 1973).*

Origin of the Iron Formation

The sedimentary succession in the Triana area is dominated by terriginous and chemically precipitated sediments, including quartzites, arkoses, pelites and iron formation. The amphibolite could represent alternating terriginous sediments derived from a continental or flanking offshore volcanic land mass. Alternatively, it may have been derived from interlayered tuffs and continental sediments. The (amphibole-garnet-) biotite gneisses could represent interlayered continentally and volcanically derived terriginous sediments deposited in a deepening basin. The seemingly large proportion of sedimentary rocks and the lack of readily identifiable volcanic rocks suggest that the iron formation was precipitated on a stable continental margin under conditions similar to those that produced the Superior-type iron formations (James, 1954; Gross, 1965).

Structure

The rocks generally trend east and have northwesterly dips ranging from 40° to vertical. Evidence revealed by small-scale folds and the outcrop pattern of the iron formation indicates at least two periods of folding, followed by late intrusive activity and subsequent faulting. The earliest deformation (D_1) apparently produced tight to isoclinal folds (F_1) accompanied by a penetrative foliation (S_1) that more or less parallels the original bedding (S_0). Fold axes of the F_1 folds appear to have had moderate northerly plunges with northeast-striking, northwest-dipping axial planes. A subsequent deformation (D_2) is characterized by open folds (F_2) which have westerly dipping axial planes; where superimposed on D_1 structures, this has produced fold interference patterns of Ramsay's (1967) Type 3. Interference patterns of Type 2 and intermediate between Types 1 and 2 also occur. Figure 4 shows the possible development of the outcrop pattern and apparent thickening of the iron formation by the interference of D_1 and D_2 structures.

A northerly trending fault that forms the north bay of Isics Lake offsets the iron formation about 450 m to the north. According to Triana Exploration Limited, the iron-bearing horizon continues eastward from Isics Lake and disappears against the Black Lake Shear Zone. Evidence from drag-folding (Johnston, 1963; Assessment File 74P03-NW-0001) suggests left-lateral movement along this fault, while interpretation of aeromagnetic data (Geological Survey of Canada, 1961) suggests right lateral movement.

Geochemistry

A composite grab sample of the iron formation between Isics and Section Lakes (Figure 2), taken by

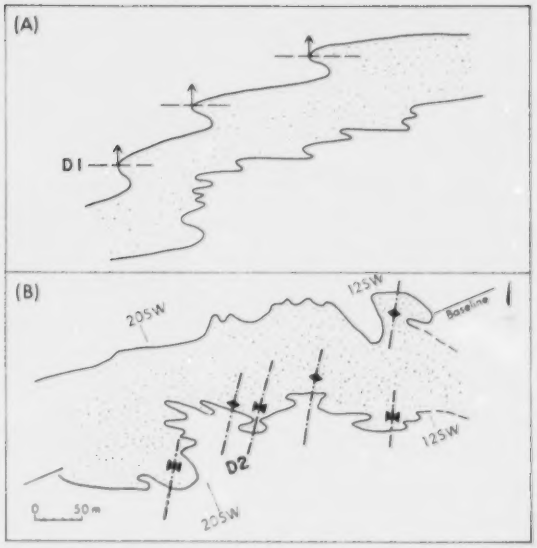


Figure 4. Structural deformation of the iron formation at the Triana deposit (after Langenberg, 1973): A, D_1 tight to isoclinal folds showing presumed orientation of axial plane traces and plunge of fold axes; B, interference pattern developed following superposition of open D_2 folds on D_1 structures.

Triana Exploration Limited, assayed 38 percent Fe (Table 4). Channel samples of 5.5, 4.6, 21.0 and 14.6 m (18, 15, 69 and 48 feet, respectively) were collected at 0.9 m (3 foot) intervals across bands of iron formation at the east end of Section Lake (Figure 2). A 0.9 m (3 foot) portion of the last sample assayed 52.32 percent Fe. An additional 31.1 m (102 feet) of iron formation, sampled at Section Lake, had a weighted average of 36.7 percent Fe. Triana Exploration Limited excavated three trenches just west of Isics Lake; a 113 kg (250 pound) bulk sample gave an assay of 34.63 percent Fe. A 23 kg (50 pound) sample from the same area, collected for concentration tests, contained an average of 38.24 percent Fe. A concentrate produced from this sample contained 64.92 percent Fe and 7.78 percent SiO_2, with a recovery ratio of 41.47 percent. Additional concentration tests returned similar values (Table 4). Analyses of representative samples yielded no titanium and neglible sulphur and phosphorus.

Geophysics

Triana Exploration Limited conducted an airborne magnetic survey in 1956 that indicated an extensive anomalous area west of Black Lake. A follow-up ground magnetometer survey indicated a zone of high magnetic intensity at least 6.4 km long and about 60 m wide. Outcrops of banded hematite-magnetite-quartz iron formation were found in this zone (Assessment File 74P03-NW-0001).

In 1973, MEP established a new grid extending 2100 m (7000 feet) west from Isics Lake and took magnetic

Table 4. Summary of Analytical Results, Triana Deposit

Operator	Sample Location	Number(s)	Sample Type		Interval (ft)	Length ft(m)	Fe wt. %
Triana Exploration Limited	East end of Section Lake	#201 - 206	Channel		0-18	18(5.5)	31.47
		#207	"		18-21	3(0.9)	7.91
		#208 - 212	"		0-15	15(4.6)	31.77
		#213 - 235	"		0-69	69(21.0)	39.15
		?[1]			0-48	48(14.6)	41.5
		?[1]				102(31.1)	36.7
	Between Isics and Section Lakes	#238 - 246	Grab				38.81
	West of Isics Lake	#237	Bulk-250 lbs (113 kg)				34.63
	Net Group #1 zone	#247	Grab			150(45.7)	25.33
	#2 zone	#248	Grab			40(12.2)	37.34
	Isics Lake	#236	Bulk-50 lbs (22.7 kg)				36.24
	From concentrates of	#236[2]					
		%Fe 64.92	67.60	67.70	68.60	69.10	70.80
		$\%SiO_2$ 7.78	4.58	3.06	3.15	3.16	1.62
							Total Fe
Mineral Evaluation Program	Section 23+00 B/L	#0+00-1+08N	Channel	at 1 ft		108(32.9)	28.36
	Section 17+80 B/L	#0+705-0+515	"	"		20(6.1)	26.12
		#0+505-0+245	"	"		28(8.5)	10.12
		#0+235-0+57N	"	"		81(24.7)	35.54
		#0+8W-1+17N	"	"		37(11.3)	31.69
	Section Area #2	#0+68W-0+27E	"	"		26(7.9)	29.29
	Section Area #3	#0+100-0+64N	"	"		64(19.5)	28.37

[1]Sample numbers not available

[2]Concentrate test results reported in Northern Miner (1957)

readings at 15 m (50 foot) intervals along lines spaced 30 m (100 feet) apart. This survey revealed that many of the magnetic highs outlined by Triana Exploration Limited are due to diabase intrusions. Therefore, the zone of anomalous magnetic intensity discovered by Triana does not correspond to a continuous band of iron formation.

Economic Evaluation

The rocks in the Black Lake area have undergone middle to upper amphibolite facies metamorphism, with resultant coarsening of grain size. Consequently, the iron formation should be amenable in the milling process to relatively coarse grinding and would qualify as a metataconite deposit. Concentration tests carried out by Triana Exploration Limited indicated that there may be some problems extracting the iron from the ore.

There is considerable variation in the deposit size and tonnage reported by the previous workers. Triana Exploration Limited indicated that deposits at Isics, Section and Mag Lakes contain 1 200 000 to 1 500 000 tonnes per vertical metre (400,000 to 500,000 tons per vertical foot), for a total of approximately 145 to 180 million tonnes (160 to 200 million tons) grading between 30 and 40 percent Fe. These estimates, however, include iron concentrations associated with diabase intrusions and substantial bands of interlayered metasedimentary rocks that contain neglible iron mineralization (Assessment File 74P03-NW-0001); thus, they are probably too high.

Langenburg (1973) calculated that the Isics Lake deposit contained reserves of 141 700 tonnes per vertical metre (47,600 tons per vertical foot) grading 34.6 percent Fe (Triana's grade). Mining to a depth of 120 m (400 feet) would increase the reserves to 17 million tonnes (19 million tons) of ore. Using Langenburg's data, Pearson (1973) estimated, from the widest section of iron formation at Isics Lake, a deposit of 113 000 tonnes per vertical metre (38,000 tons per vertical foot) or 17 million tonnes (19 million tons) grading 30 to 34 percent Fe, if mined to a depth of 150 m (500 feet). Diabase dykes up to 18 m (60 feet) wide and interlayered biotite gneisses ranging from 0.3 to 3 m (1 to 10 feet) in thickness suggest a dilution factor of about 20 percent.

The entire length of the iron formation at Isics Lake, including the portion beneath the lake, could be open pitted, although high waste-to-ore ratios would be encountered along some sections of the deposit. The deposit would be about 1200 m (4000 feet) long with an average width of 75 m (245 feet). Using a density of 3810 kg/m^3 (238 pounds per cubic foot) and a mineable depth of 150 m (500 feet), a deposit of approximately 53 million tonnes (58 million tons)

grading between 30 and 34 percent Fe is indicated. A 20 percent dilution indicates approximately 10.5 million tonnes (11.6 million tons) of waste within the deposit. Expected tonnage could be reduced substantially if the iron formation is truncated at depth. Since no diamond drilling has been undertaken on this deposit, the nature of the iron formation and intrusives at depth is not known.

Additional reserves could be provided by the adjacent but smaller deposits at Section and Mag Lakes; the deposit at Section Lake is richer (Table 4), although it has a total thickness of only 46 m (150 feet). Despite insufficient data, there is considered to be insufficient tonnage to justify development in both these locations. Even if a combined tonnage of 100 million tonnes or more could be achieved, the high transportation costs would still render the deposits economically undesirable.

In conclusion, the Triana iron deposits must be considered uneconomic at present because of their low tonnage, poor iron recovery and geographic remoteness. Future consideration could be given to the deposits if a road is constructed to Black Lake and/or the price of iron ore reaches a level where smaller deposits such as Triana could be mined.

VH (Nyberg Lakes)

A low-level airborne magnetometer survey carried out by C.A.L. Hogg in 1959 in the Virgin River area led to the discovery of banded magnetite-bearing iron formation three miles east of Nyberg Lakes (Hogg, personal communication, 1981). Following confirmation of the size of the anomaly by a 1962 airborne magnetometer survey flown by Canadian Aero Services Limited (see also Geological Survey of Canada, 1964b) and favourable geochemical results, Hogg staked 18 claims, VH 19 to 36, to cover the anomaly (Assessment File 74G04-NE-0018). On the basis of a ground magnetometer survey and geochemical results from thirteen grab samples, Hogg estimated there to be possible reserves of 24 million tonnes (27 million tons) to a vertical depth of 45 m (150 feet) grading 40 percent Fe. In 1966, Kenad Developments optioned the property and completed two diamond-drill holes totalling 345 m (1131 feet). Neither hole was assayed but, based on previous work by Hogg, Kenad estimated possible reserves of 136 million tonnes (150 million tons) grading 42.2 percent Fe to a depth of 150 m (500 feet) (Assessment File 74G04-NE-0008). Kenad allowed the option to lapse and the claims reverted to Hogg.

In January 1973, the claims were converted to mineral lease ML 5109. Later that year, as part of the MEP investigation of iron deposits, Langenburg (1973) and McDougall (1973) carried out geological and ground magnetometer surveys, respectively, on the property. Langenburg estimated ore reserves to be only 27 million tonnes (30 million tons) grading 32 percent Fe to a depth of 150 m (500 feet).

The property was re-evaluated for Hogg (now Flin Flon Mines Limited) in 1974 by Northland Exploration Services Limited and Kenting Exploration Services Limited. Northland carried out radiometric and bedrock and soil geochemical surveys, and Kenting completed a computer study of the deposit based on the MEP magnetometer survey and earlier geochemical results. The magnetometer survey of the property was rerun in 1977 by Northland and further metallurgical tests were completed in 1979 by Lakefield Research of Canada Limited for Flin Flon Mines Limited. A 1981 prefeasibility overview by Morton and Partners Limited indicated possible reserves of 113 to 150 million tonnes to a depth of 150 million tonnes to a depth of 150 m and suggested further investigation of the property. In October 1981, T.R.B. Dundas and Associates Limited completed detailed gravity and vertical field magnetic surveys of the property and made new bulk volume estimates of the deposit (Hogg, personal communication, 1982; Assessment File 74G04-NE-0024).

General Geology

The VH deposit lies within a small synformal remnant of Aphebian supracrustal rocks surrounded by Archean granitoid gneisses (Figure 5) in the Virgin River Domain. Rocks of the Archean infrastructure have been variously described as granite and granitic gneiss (Sproule and Downie, 1941), quartz monzonitic gneisses (Johnson, 1968) and felsic gneisses (Wallis, 1970; Langenburg, 1973; Gilboy, 1977). The northeasterly trending synform contains pelite, quartzite, and banded iron formation metamorphosed to upper amphibolite grade and apparently intruded by small bodies of anatectic granite (Langenburg, 1973).

Rock Descriptions

The types and distribution of rock units recognized by Langenburg (1973) in the vicinity of the VH deposit are shown in Figure 5. For convenience, a group of apparently gradational rock units including iron formation, garnetiferous quartzite and garnet-biotite gneiss will be described together as the VH formation. The rock descriptions that follow are based on Langenburg's (1973) and this author's interpretations.

Felsic gneisses entirely enclose the synformal remnant and are the lowest structural unit present.

They are pale grey to pale pink with slightly redder bands in places, moderately foliated and composed mainly of quartz, feldspar and biotite.

Dark green, commonly massive bands of **amphibolite** are interlayered with the felsic gneiss. Hornblende is the main mineral phase, with subordinate feldspar, biotite and quartz.

Well-foliated **garnet-biotite gneisses** both enclose and alternate with the bands of the VH formation. The foliation, marked by the preferred orientation of biotite, is generally parallel to lithologic layering. The rocks are dominantly quartzofeldspathic but commonly contain 25 percent or more of biotite and garnet, with sillimanite and green amphibole common in places and cordierite present locally. Migmatization of these rocks has produced anatectic granitic veins, dykes and sills that have invaded the gneisses. The larger bodies are shown in Figure 5.

The **VH formation** includes garnet-biotite gneisses containing lithic fragments, garnetiferous quartzites with or without magnetite, and banded quartz-magnetite iron formation. According to Langenburg (1973) these rocks comprise a gradational sequence, but he could not determine whether their present distribution results from extensional deformation or facies variation. Langenburg identified three distinct layers of iron formation with accompanying garnetiferous quartzites, but was not certain whether they represented the same layer complexly folded or a cyclic succession.

The garnet-biotite gneiss with fragments of other rock types appears (Langenburg, 1973) to be the same garnet-biotite gneiss described above, but contains disrupted and sometimes folded boudinaged layers of garnetiferous quartzite and/or iron formation.

The garnetiferous quartzite is commonly associated with the iron formation and is gradational with both the magnetite-bearing variety and the iron formation. The quartzites are typically brown-red and contain as much as 50 percent garnet, along with minor amounts of green amphibole, diopside and biotite.

The magnetite-bearing garnetiferous quartzite always occurs near the iron formation, forming a gradational facies between the iron formation and the garnetiferous quartzite. The unit is essentially similar to the garnetiferous quartzite except for the obvious concentration of magnetite.

Banded iron formation occurs in three horizons (15 to 90 m thick) which appear to pinch out along strike and are truncated by granitic bodies. The iron formation, typically a blue metallic colour because of the magnetite content, consists of 1 to 10 mm thick quartz-rich layers containing garnet, green amphibole and/or diopside in alternation with magnetite-quartz-rich layers.

The banded nature and mineralogy of the iron formation and associated metasediments suggest that perhaps it was originally a cherty, oxide-silicate iron formation that graded laterally into iron silicate facies iron formation. The latter is now represented by the garnetiferous quartzite.

The larger bodies of **granite** shown in Figure 5 cut across second-generation structures and contain inclusions of garnet-biotite gneiss. They consist mainly of quartz, feldspar and biotite, and locally contain abundant garnet. The granites are undoubtedly anatectic melts derived from the enclosing metasediments, formed in or intruded into hinge zones, boudin necks or other zones of weakness.

Origin of the Iron Formation

The supracrustal rocks associated with the VH deposit, mainly pelites and quartzites, are characterized by a lack of undisputed metavolcanic rocks, although some amphibolites were encountered in drill holes. Because high-grade metamorphism and intense deformation have erased most original sedimentary structures, the origin of the iron formation remains speculative. The meagre evidence available suggests that the VH iron deposit probably formed under conditions similar to those described for the Superior-type iron formations (Gross, 1965).

Structure

The VH deposit occurs in a northeasterly trending synform offset by a northwesterly trending transverse fault. The synform is considered to be the result of interference of at least three major episodes of folding (Lewry and Sibbald, 1977; Sibbald et al., 1977). Layering in the iron formation may represent primary sedimentary bedding which is parallelled in most cases by a well-developed penetrative foliation believed to have formed during the earliest phase of isoclinal folding. This folding is thought to be coeval with Lewry and Sibbald's (1977) period of recumbent migmatite lobe and mantled gneiss dome formation. Following the first phase, the region was deformed into Type 1 (Ramsay, 1967) dome-and-basin interference patterns along "two suborthogonally oriented fold sets whose axial surfaces are subvertical and, on average, northwesterly (D_2) and northeasterly (D_3) trending" (Lewry and Sibbald, 1977, p. 1459). Subsequent transverse faulting

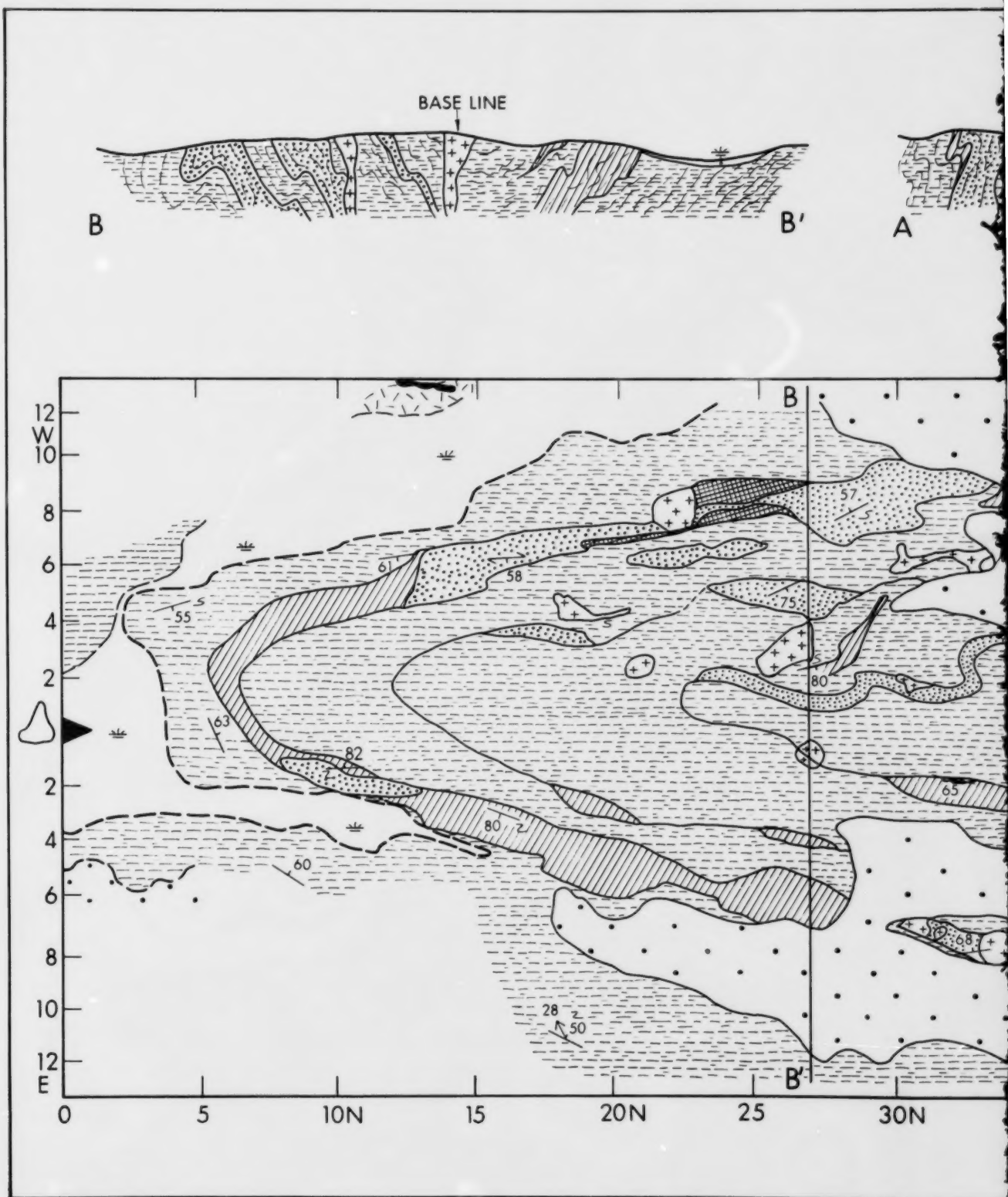
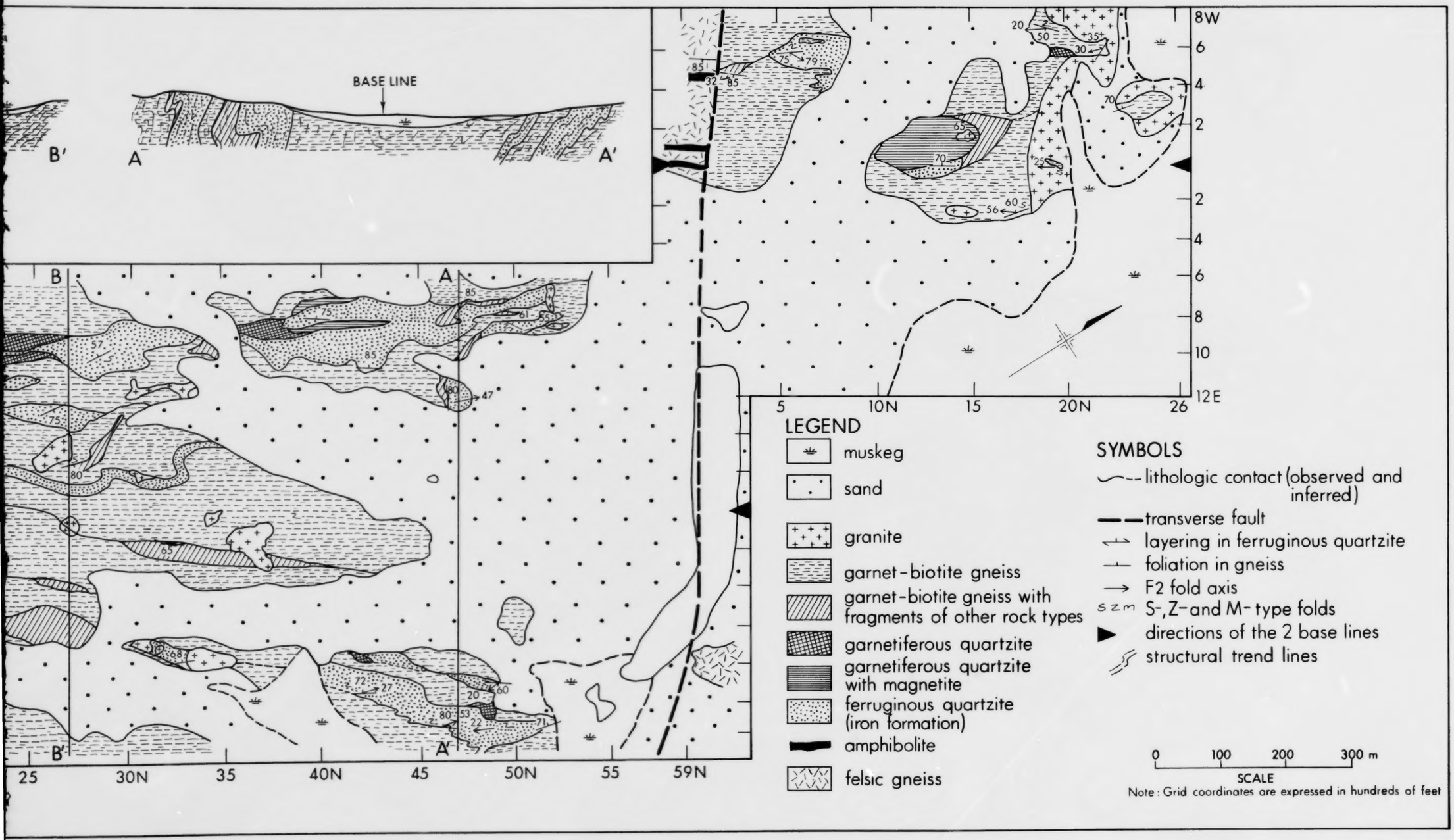


Figure 5. *Geology of the VH iron deposit (after Langenberg, 1973).*


BASE LINE
B'
A
A'
B
A
B'
A'
8W
6
4
2
2
4
6
8
10
12E
5
10N
15
20N
26
25
30N
35
40N
45
50N
55
59N
LEGEND
muskeg
sand
granite
garnet-biotite gneiss
garnet-biotite gneiss with fragments of other rock types
garnetiferous quartzite
garnetiferous quartzite with magnetite
ferruginous quartzite (iron formation)
amphibolite
felsic gneiss
SYMBOLS
lithologic contact (observed and inferred)
transverse fault
layering in ferruginous quartzite
foliation in gneiss
F2 fold axis
S-, Z- and M- type folds
directions of the 2 base lines
structural trend lines
0
100
200
300 m
SCALE
Note: Grid coordinates are expressed in hundreds of feet

separated the VH synform by about 1 km into northern and southern parts (Figures 5 and 6).

Stereographic plots indicate that the synform has subvertical northeasterly trending axial planes (Langenburg, 1973). The southern part of the synform has steep dips with the axis plunging 49 to 59° at 021 to 037°, whereas the northern part has shallow dips with the axis plunging 13 to 20° at 204°.

Based on the idea of a single iron formation unit, Figure 6 shows the author's interpretation of a plausible sequence of events leading to the formation of the synform, a sequence which explains the repetitive stratigraphy in the VH deposit.

Geochemistry

Analytical results from the VH deposit are summarized in Table 5. Following the discovery of iron formation in 1962, a single grab sample taken by Hogg assayed 45.12 percent acid soluble Fe. A concentrate containing 69.09 percent acid soluble Fe produced 44.49 percent magnetic Fe, giving a recovery of 98.6 percent. On a sieve analysis, almost 95 percent of the sample was retained at -325 mesh. However, it was felt that good grade and recovery could still be achieved at a much coarser grind (Assessment File 74G04-NE-0018).

Thirteen additional samples (A1 to A13, Table 5) collected by Hogg in 1962 averaged 42.2 percent total Fe. All impurities proved to have consistently low concentrations. It was also shown that most samples could be satisfactorily concentrated at -200 mesh; some samples with more than 5 percent SiO_2, rerun at -325 mesh, showed a decrease to 1 to 3 percent SiO_2.

A 21 m (70 foot) section of outcrop, chip sampled at 0.6 m (2 foot) intervals by MEP and assayed for iron, averaged 32 percent Fe for 32 samples (Langenburg, 1973; Pearson, 1973).

Northland Exploration Services Limited carried out a bedrock and soil geochemistry survey in 1974 (Assessment File 74G04-NE-0020). Soil samples were analyzed for Cu and Zn and, although minor and erratic copper mineralization was indicated, no significant anomalies were detected. The 50 bedrock

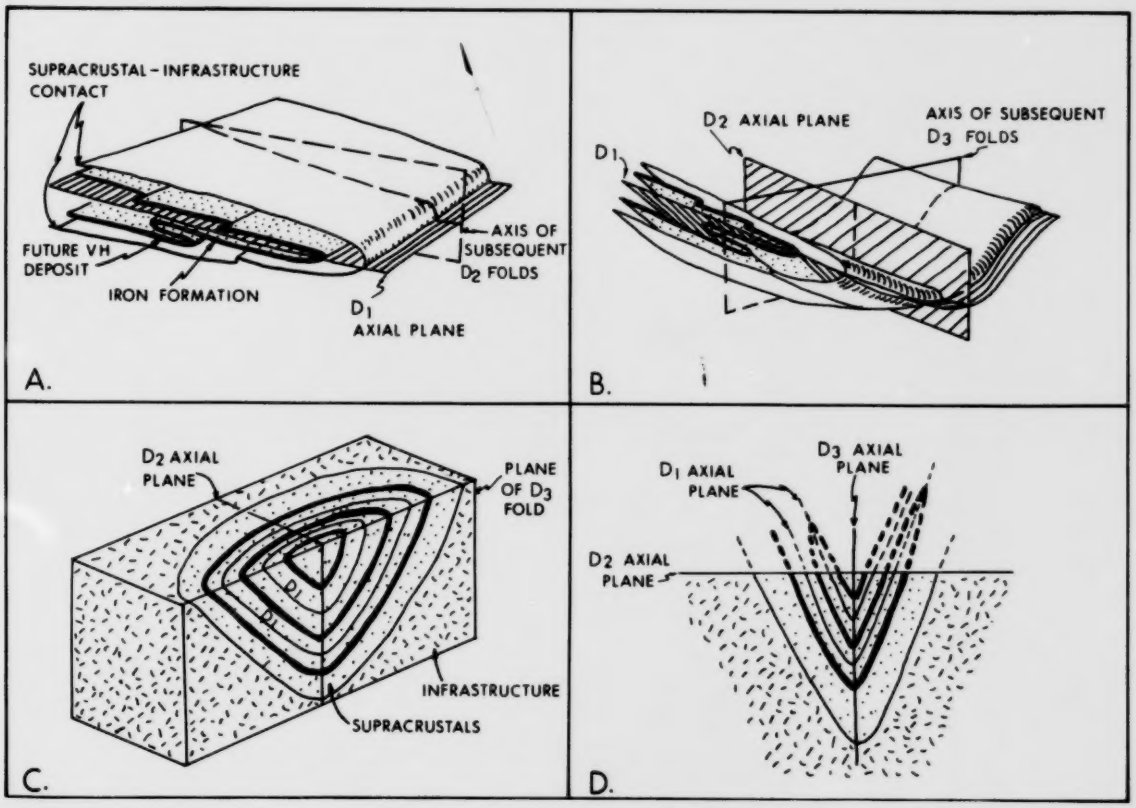


Figure 6. *Possible structural development of the VH iron deposit: A, D_1 migmatite lobe stage, with large parasitic fold at future site of VH deposit; B, post-D_2 stage; C, post-D_3 stage (schematic block diagram to present erosion level); D, cross-section along D_2 axial trace.*

Table 5. Summary of Analytical Results, VH Deposit. All Values in Weight Percent

Sampler(Year); Analyst	Type of Analysis & Number		Crude			Concentrate			Tails										
			Sol	Total Fe	SiO_2 Fe	Fe	Sol Fe	Total Fe	Sol Fe	Total Fe	SiO_2[2] Fe	P	S	Al_2O_3	CaO	MgO	MnO	TiO_2
Hogg (1962); Lakefield Research of Canada Limited	Direct		45.12		27.24							0.38	0.05				1.26	0.06
	Davis Tube					64.4	69.09		35.6	1.76[1]	0.32					0.40	0.08	
Hogg (1962); Picklands Mather Laboratory	Direct and Davis Tube (−200 Mesh)	A1		42.66	30.50	54.87		68.72		10.98	2.84	0.024	0.012					
		A2		40.54	32.12	46.87		66.79		17.38	4.15							
		A3		33.30	33.36	30.40		62.05	9.29	20.74	9.43							
		A4		40.98	28.04	50.57		66.31		15.07	4.70							
		A5		45.94	23.12	58.40		66.71		16.78	3.82							
		A6		43.42	28.66	57.00		62.29	2.93	18.40	9.57							
		A7		49.15	23.32	66.20		68.16		11.92	3.02							
		A8		33.70	36.90	41.33		59.15		15.73	9.72	0.039	0.018	3.56	0.26	0.33	0.26	0.22
		A9		29.58	30.96	33.00		57.39		15.88	8.67	0.057	0.021	2.16	0.14	0.26	1.05	0.12
		A10		44.10	25.74	57.87		63.49		17.47	7.06							
		A11		48.84	23.56	59.13		68.64	8.31	20.19	1.84							
		A12		46.82	25.22	50.27		66.07	26.58	27.36	4.86							
		A13		49.62	24.48	68.13		67.51		11.41	4.01							
	Reruns (−325 Mesh)	A3		33.30	33.36	28.07		64.38		20.88	8.39							
		A6		43.42	28.66	52.13		66.01		18.82	7.34							
		A8		33.70	36.90	35.67		65.20		16.23	6.44							
		A9		29.58	30.96	27.53		64.38		16.37	5.93							
		A10		44.10	25.74	54.00		66.67		17.60	5.40							
MEP (1973) University of Regina	Direct 32 Samples			32 (average)														

[1]Acid soluble Fe

[2]SiO_2 values in samples A1 to A13 are from concentrate

samples collected included a variety of grab, chip and channel samples, but there is little indication of sample intervals and lengths. The average of 21 samples analyzed at 100 percent -200 mesh is 32.58 percent magnetic Fe in the ore.

In 1979 Lakefield Research of Canada Limited carried out iron recovery tests on two samples submitted by Flin Flon Mines Limited (Hogg, personal communication, 1981). Using stage-grinding to -400 mesh, with between-stage magnetic concentration and cationic silica flotation in the last stage, a super-concentrate containing 70.37 percent Fe and 1.13 percent SiO_2 was produced from one sample. The other sample, however, could not be as successfully upgraded, yielding a concentrate with 64.77 percent Fe and 5.78 percent SiO_2.

The chemical results indicate the ore is of acceptable purity and that parts of the ore may produce a super-concentrate of very low silica content acceptable for direct reduction if silica can be kept below 2 percent. Although the latest testing did not include analyses of deleterious elements, Davis tube tests conducted in 1962 by Lakefield Research (Assessment File 74G04-NE-0018) indicated that titanium and other impurities can be successfully reduced to acceptable levels.

Geophysics

A ground magnetometer survey was carried out over the VH deposit by MEP (see Table 1); readings were taken at about 15 m (50 foot) intervals along lines spaced about 30 m (100 feet) apart and the results were plotted at a scale of 1:2400 and contoured on a 1000 gamma interval (McDougall, 1973). A constant anomalous reading of 65 523±2 gammas was recorded over the iron formation, with the highest readings occurring along contacts between the iron formation and the garnet-biotite gneiss or near small gneiss inclusions within the iron formation. Because the 65 000 gamma contour included areas of waste, it could not be used to determine the size of the deposit or its magnetite content.

The survey not only substantiated the structural evidence in defining synform, but also showed that the bulk of the ore deposit lies on the west side of the synform. It also revealed a northwest-trending transverse fault, as well as two other possible shear zones trending northest and north but with no apparent displacement.

Northland Exploration Services Limited, using both Geometrics G-816 and Scintrex MP-2 portable magnetometers, resurveyed the VH property in 1977 to compare the results from the two instruments, to better define the boundaries between gneiss and iron formation, and to reassess the tonnage estimates on the basis of the new magnetic survey. Magnetic readings in excess of the MP-2 instrument's 100 000 gamma limit corresponded to the highest iron assays obtained in the 1974 bedrock geochemical survey. These results were resubmitted to Kenting Exploration Services Limited for revision of tonnage estimates.

T.R.B. Dundas and Associates Limited, using a Lacoste gravity meter and vertical field Fluxgate magnetometer, resurveyed the property in 1981 to evaluate the density contrast between the host rocks and the iron ore, and thereby give bulk volume estimates of the ore.

Economic Evaluation

Detailed petrographic descriptions of the ore have not been reported, but because the VH deposit has undergone middle to upper amphibolite metamorphism, the iron formation has been classed as a metataconite-type deposit. It should be amenable to relatively coarse grinding, but recovery tests have shown that the best concentration was achieved on -400 mesh material. The ore is satisfactory as a non-Bessemer ore.

Tonnage calculations have varied considerably. The original estimate (Assessment File 74G04-NE-0018) for a deposit about 2700 m (9000 feet) long by 45 to 60 m (150 to 200 feet) wide and up to 45 m (150 feet) deep gave possible reserves of 18 to 24 million tonnes (20 to 27 million tons) grading 40 percent Fe. If mineable to 150 m (500 feet), reserves would be 60 to 82 million tonnes (66 to 90 million tons). In 1966 possible reserves of 136 million tonnes (150 million tons) grading 42.2 percent Fe (the average iron content of samples A1 to A13) were estimated on the basis of a ground magnetometer survey (Assessment File 74G04-NE-0008). Results from two diamond-drill holes indicated that the deposit thinned at depth (Pearson, 1973).

Langenburg (1973) estimated there to be five main ore lenses with a combined surface area of 51 000 m^2 (550,000 square feet) containing iron ore grading 32 percent Fe with a specific gravity of 3.7, or 3700 kg of ore per m^3 (230 pounds per cubic foot). If mined to a depth of 150 m (500 feet), the deposit could have possible reserves of 27 million tonnes (30 million tons). Pearson's (1973) evaluation of the deposit indicated possible reserves of 23 million tonnes (25 million tons) to a depth of about 150 m (500 feet). He also stated that, not only do "the ore bodies pinch out along strike, [but] it is possible that they pinch out at depth" (ibid, p.10). The reserves would thus diminish proportionately.

In 1974 Northland Exploration Services Limited and Kenting Exploration Services Limited estimated possible ore reserves of 109.4 million tonnes (120.6 million tons) and 93.5 million tonnes (103.1 million tons) respectively, grading 30 to 35 percent Fe. The Northland estimate was based on the total surface area of iron formation mineable to a depth of about 150 m (500 feet). The Kenting estimate was based on the magnetometer survey of 1973 and also assumed a mineable depth of 150 m. On the basis of the 1977 magnetometer survey, Kenting believed its original calculation to be conservative, and again recommended that a detailed gravity survey be carried out over the property.

A prefeasibility study by Morton and Partners in 1981 estimated possible reserves of 113 to 150 million tonnes to a depth of 150 m, with higher reserves possible if mining could be taken successfully to greater depths (240 m). The report by T.R.B. Dundas and Associates Limited identified two categories of ore, massive and disseminated. Bulk volume estimates indicate 56.5 million tonnes (62.2 million tons) of massive ore containing 65.3 percent magnetite and 400 million tonnes (440 million tons) of disseminated ore containing 32.7 percent magnetite (Assessment File 74G04-NE-0024; Northern Miner, 1982).

The VH deposit is geographically remote, being situated about midway (80 to 90 km) between all-weather gravel highways to Key Lake and Cluff Lake (Figure 1, in pocket). As Flin Flon Mines Limited has plans for further exploration in 1982, and in view of the current (1982) economic conditions, the status of the deposit is still uncertain. However, should the deposit be developed, Flin Flon Mines is considering construction of a slurry pipeline as a possible option for shipping concentrate to northeastern Alberta (Northern Miner, 1982).

Ithingo Lake

Sproule (1938) was first to report the presence of magnetite in association with pyrite, chalcopyrite, arsenopyrite and sphalerite occurrences in quartzites of the Ithingo Lake area. Other reports of banded iron formation from this area (Mawdsley, 1960) prompted the Saskatchewan Department of Mineral Resources to carry out an airborne magnetic survey over part of the area in 1954. That survey indicated a number of magnetic anomalies, two of which, located south of Ithingo Lake (Figure 7), were investigated as part of a ground follow-up (Mawdsley, 1960). The western anomaly, examined in outcrop and trenches, showed a sequence of quartzites and banded quartz-magnetite ± pyrrhotite iron formation. Mineralization was considered uneconomic. No comment was made on the potential of the eastern deposit because it is almost entirely buried beneath glacial moraine.

Between 1957 and 1974, claims were held in the Ithingo Lake area by G. Hall, Silver Chief Minerals Limited and Canadian Nickel Company Limited. In each case, the claims were allowed to lapse after some work had been carried out (Assessment Files 74B13-SE-0001 and 74B13-NE-0003).

The two magnetic anomalies south of Ithingo Lake (see Table 1) were examined during this project because they provided an opportunity to compare a ground magnetic anomaly associated with an exposed iron formation with an unexplained anomaly in an area where glacial deposits completely mantle the bedrock.

Geology

The Ithingo West and East iron occurrences are located in adjoining basin-and-dome structures in the Mudjatik Domain. Basement granite gneisses are infolded with supracrustal mafic granulites, psammitic, pelitic and semipelitic gneisses, calc-silicates, marbles and iron formation. All are affected by upper amphibolite to lower granulite facies metamorphism (Sibbald, 1973).

The general geology is shown in Figure 7. More detailed maps of the West and East occurrences are given in Figures 8 and 9 respectively.

A prominent feature of the Ithingo Lake area is the thick east-southeasterly trending glacial moraine, which forms the highest hills in the area and accounts for the poor exposure in the vicinity of the East occurrence. Glacial outwash sands are common throughout the area; other glacial features such as kettle holes, eskers and till occur locally.

Rock Descriptions

Structural complexity makes stratigraphic studies difficult. The succession depicted in Figure 8 for the Ithingo West occurrence and described below indicates structural but not necessarily stratigraphic order.

Gneissic granite (Unit 1) occurs on the northwest, east and southeast sides of the West occurrence, and on the high ridge connecting the two occurrences (Figure 7). In the east and southeast, the gneissic granites are typically coarse grained, foliated and pink on both fresh and weathered surfaces, and blocky jointing is common. Mafic minerals, generally biotite, make up less than 10 percent of the rock. At the East occurrence, xenoliths

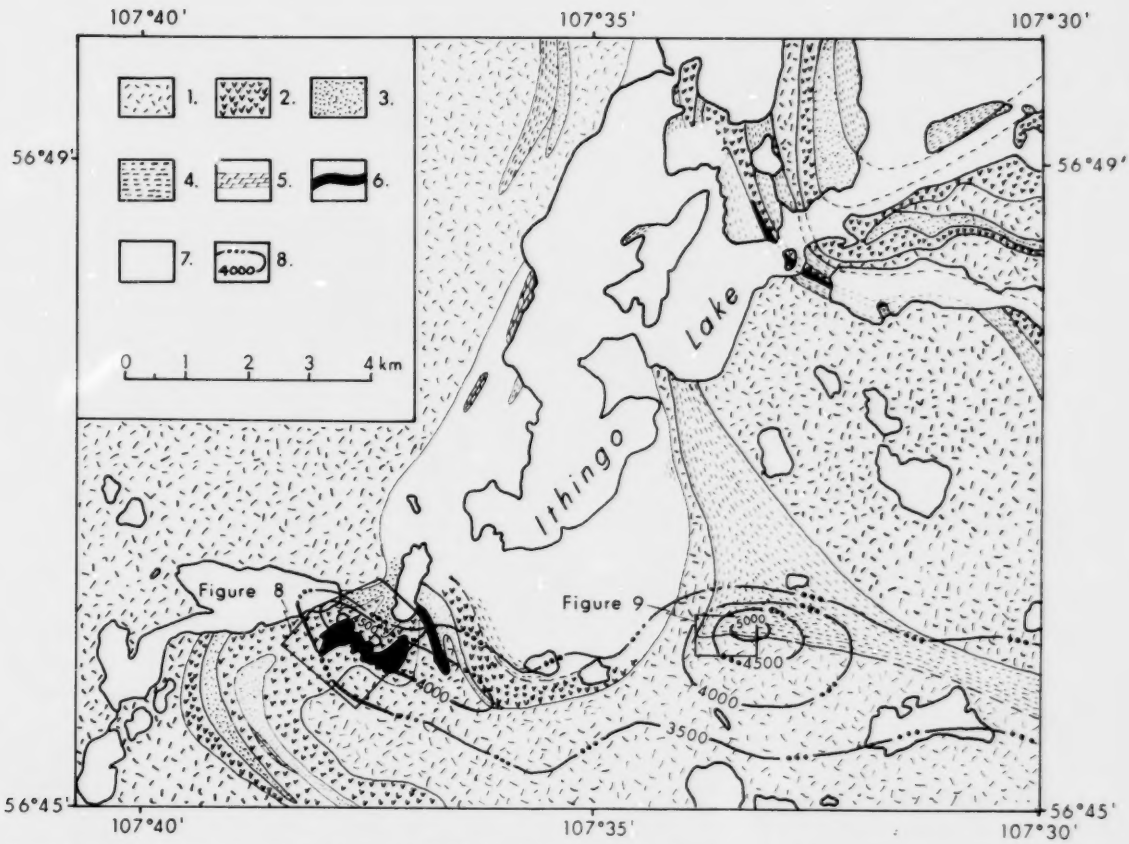


Figure 7. *Geologic setting of the Ithingo Lake area (modified from Sibbald, 1973). 1, granitic and felsic gneisses; 2, mafic granulites of uncertain origin, hornblende, diopside, hypersthene, plagioclase rocks; 3, psammitic gneisses, may contain up to 10 percent of one or more of biotite, garnet, cordierite, magnetite and sillimanite; 4, semipelitic gneisses, containing 10 to 25 percent of same minerals as Unit 3 plus graphite; calc-silicate gneisses, dominantly diopside-plagioclase and impure marbles, containing forsterite, diopside, spinel and phlogopite; 6, banded quartz-magnetite iron formation and associated rocks; 7, undifferentiated metasediments (largely drift covered); 8, aeromagnetic contours associated with iron occurrences.*

of iron formation and biotite-hornblende gneiss are enclosed by gneissic granite. In the northwest, the gneissic granite is less homogeneous, more mafic (containing up to 20 percent combined biotite and hornblende), well foliated, coarse grained and strongly colour banded. The gneissic granites are in part derived from migmatized supracrustals, as they appear to grade into the biotite schist and gneiss.

Biotite schist and gneiss (Unit 2), exposed at both occurrences, are characterized by rusty brown or dark grey weathered surfaces and light to dark grey fresh surfaces; grain size varies from 1 to 3 mm. The schist and gneiss are composed of alternating biotite-poor and biotite-rich layers, 0.5 to 10 cm thick, and are interlayered with segregation pegmatite. The latter form up to 30 percent of the rock. The biotite-poor layers (less than 10 percent biotite) generally have the mineralogy of an arkose, whereas the biotite-rich layers may represent shaly partings or mafic metamorphic segregations. Garnet occurs in some layers, generally forming larger grains in the leucocratic segregations.

Amphibolite and hornblende-biotite gneiss (Unit 3) are the most abundant rock types exposed in the vicinity of the West occurrence (Figure 8). Amphibolites form part of the ridge joining the two occurrences and trend northeasterly along the western edge of the East occurrence (Figure 7). Layers of pink- to brown-weathering meta-arkose and dark grey biotite-feldspar schist are interlayered with these rocks. The coarse-grained amphibolites and hornblende-biotite gneisses are dark greenish grey on both fresh and weathered surfaces and generally have poorly developed layering, although in places a fine layering is preserved. Hornblende and plagioclase are the dominant minerals, but biotite is locally abundant. Hornblende porphyroblasts up to 1 cm long, as well as garnetiferous layers and disseminated pyrite occur in places.

Iron formation (Unit 4), ferruginous quartzite (Subunit 4a) and quartzite (Subunit 4b) are interlayered, appear to be gradational, and together range from 15 to 150 m thick. They are primarily exposed in the West occurrence, but a single exposure is present in the East occurrence (Figure 9).

The iron formation (Unit 4) occurs mainly at the western extremity of the West occurrence, where it reaches a maximum width of 90 m in the hinge zone of a synformal structure (Figure 8). It is characterized by strongly hematite- and limonite-stained quartzite, as well as magnetite, biotite-magnetite and biotite meta-arkose layers. The quartzite layers, 0.3 to 10 cm thick, are white to grey on fresh surfaces and greenish where strongly altered. They have a 1 to 2 mm grain size, contain powdery disseminated magnetite and are accompanied locally by diopside, green amphibole, garnet and biotite. Granular magnetite less than 1 mm in diameter commonly occurs in layers 1 to 3 mm thick, or in thicker lenses. In places, 5 mm magnetite grains, biotite books up to 6 mm across and garnet porphyroblasts up to 2 cm in diameter occur in layers up to 3 cm thick. Elsewhere, disseminated to massive pyrrhotite and pyrite accompany magnetite and quartz in strongly oxidized layers or zones up to 10 m thick. Masses of limonite-geothite and breccia coated and cemented by limonite-geothite occur in several trenches. The breccia is composed of angular fragments and pebbles (1 to 30 mm long) of quartzite, and sand-sized grains of quartz and magnetite. The breccia, which has a vein-like appearance, is probably weathered rubble that infilled fractures and joints and was subsequently consolidated by a limonite-geothite cement leached from the parent iron formation. Amorphous masses of limonite-geothite, commonly containing a few quartz fragments, may represent remnants of an enriched capping on the iron formation, or oxidized pockets of magnetite.

The more abundant ferruginous quartzites (Subunit 4a) are similar to the banded iron formation, although magnetite is less abundant. The biotite meta-arkoses, which are gradational into the ferruginous quartzites, generally occur as discontinuous lenses. Typically light grey in colour, they have a 1 mm grain size and locally contain garnet.

Quartzite (Subunit 4b) occurs in the cores of the two larger synformal structures at either end of the West occurrence (Figure 8). Taking into account the effect of folding, the quartzite has an estimated thickness of about 60 m. This quartzite can be distinguished from the ferruginous quartzites by massive structure or weak layering, very coarse grain size, the presence of vugs, and the occurrence of sparsely disseminated euhedral pyrite which produces a light limonitic stain on the weathered surfaces. Little or no magnetite was observed. At the northern hinge of the eastern synformal structure the quartzite is extremely granular, porous and friable, and is composed of poorly developed stubby quartz crystals that average 5 mm and range up to 10 mm in diameter.

Origin of the Iron Formation

Although the succession south of Ithingo Lake is dominated by metasediments, the amphibolite and hornblende-biotite gneisses may represent metamorphosed volcanic rocks. The general similarity between the stratigraphy of this area and that of the VH deposit suggests a common origin for the iron, similar to that of Superior-type iron formations. Mineralogically, the iron formation at Ithingo Lake represents a transitional facies which includes iron oxide, iron silicate and iron sulphide minerals.

Structure

The West occurrence is situated along the northern rim of a basin produced by fold interference patterns, while the East occurrence lies along the southern flank of a dome. The interpretation of the East occurrence is complicated by poor exposure, but this is not true for the West occurrence.

Although most primary sedimentary structures have not been preserved, bedding (S_0) is evident in the iron formation. The dominant planar structure is a metamorphic foliation which generally parallels the bedding and developed during the first isoclinal fold deformation phase. Both bedding and foliation commonly dip 60 to 70° southeast through to southwest and define large-scale fold structures. No foliations related to the second and third deformation phases were observed.

First generation folds (F_1) may be represented by small-scale isoclinal rootless folds. Small-scale second generation folds (F_2) were not recognized, but a large west-northwest-trending F_2 synform that contains the iron formation was delineated in the area of the West occurrence. This synform, on the northern rim of a larger basin, may represent a rather large parasitic fold related to an F_2 synclinorium. The F_2 synform has been severely refolded by the third generation northeast-trending F_3 folds. Seven F_3 fold closures were identified (Figure 8); it is in these closures that small-scale folds are most abundant. Large-scale F_2 and F_3 folds both have steeply dipping axial planes with variable axial plunges. The F_3 folds have steep southeast- to southwest-plunging axes (Figure 8). The southern flank of the F_2-F_3 dome which contains the East occurrence has a crescent shape, indicated both by the results of the ground

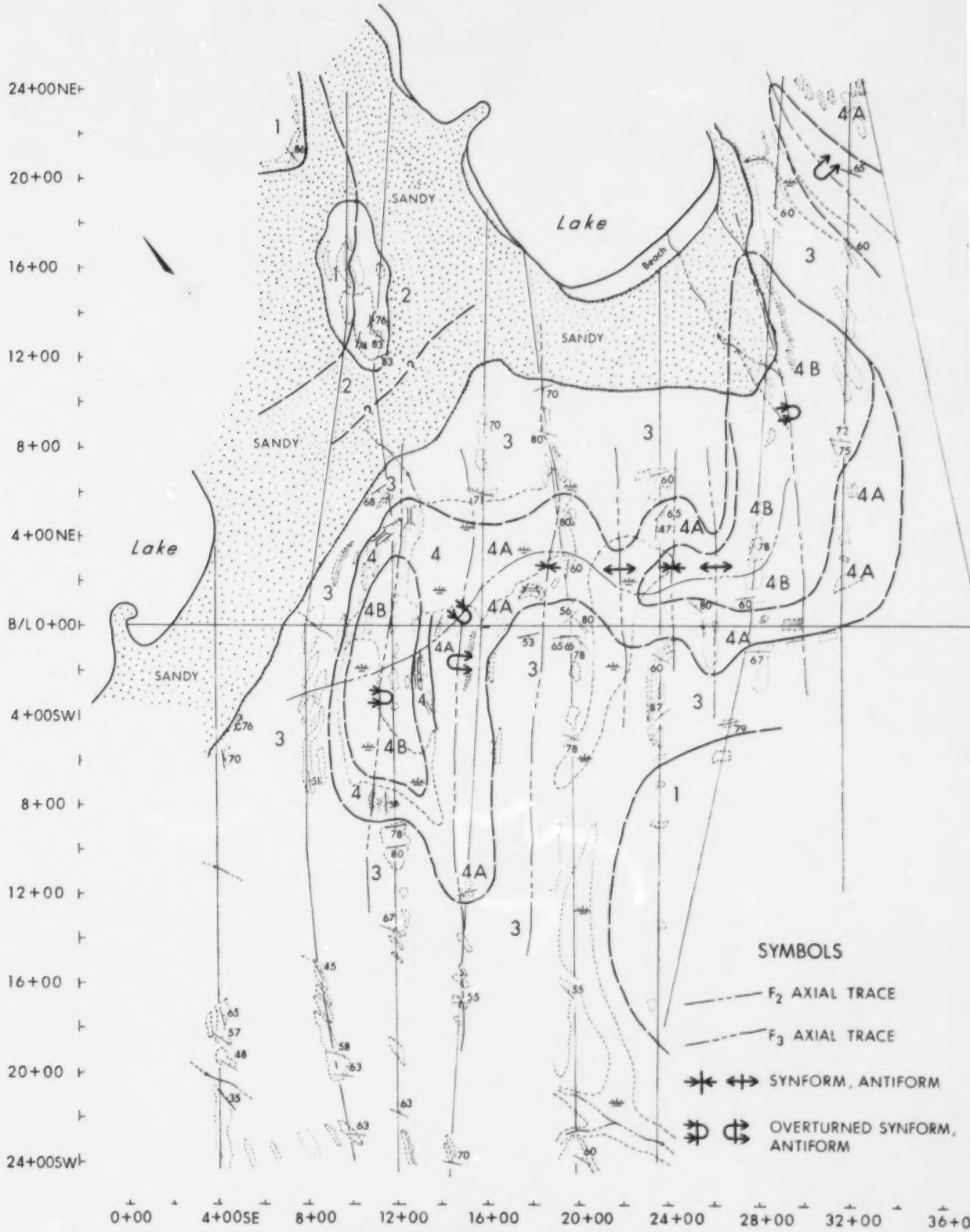
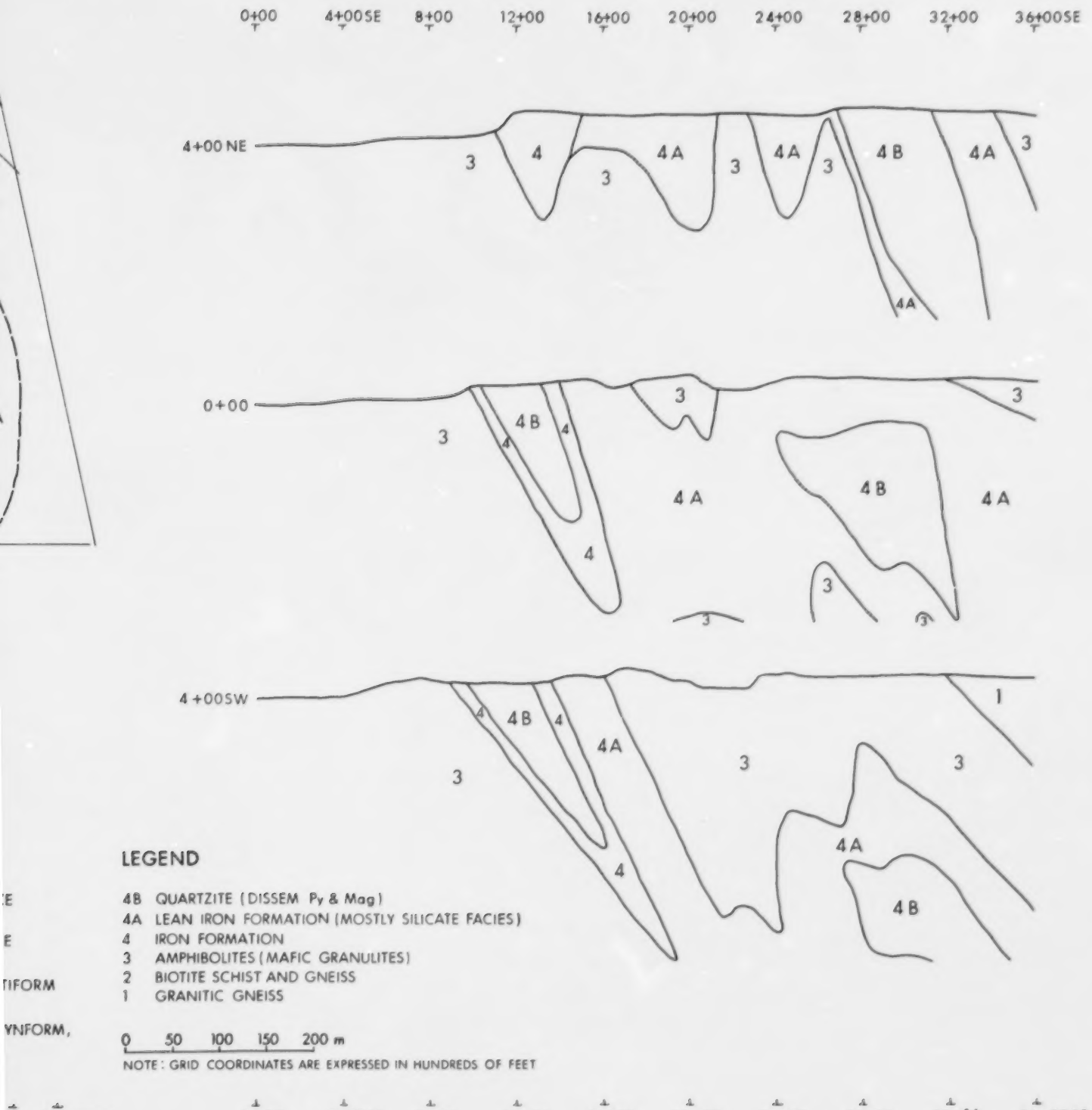


Figure 8. Geology and cross-sections of the Ithingo West occurrence.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28+00
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4+00 NE
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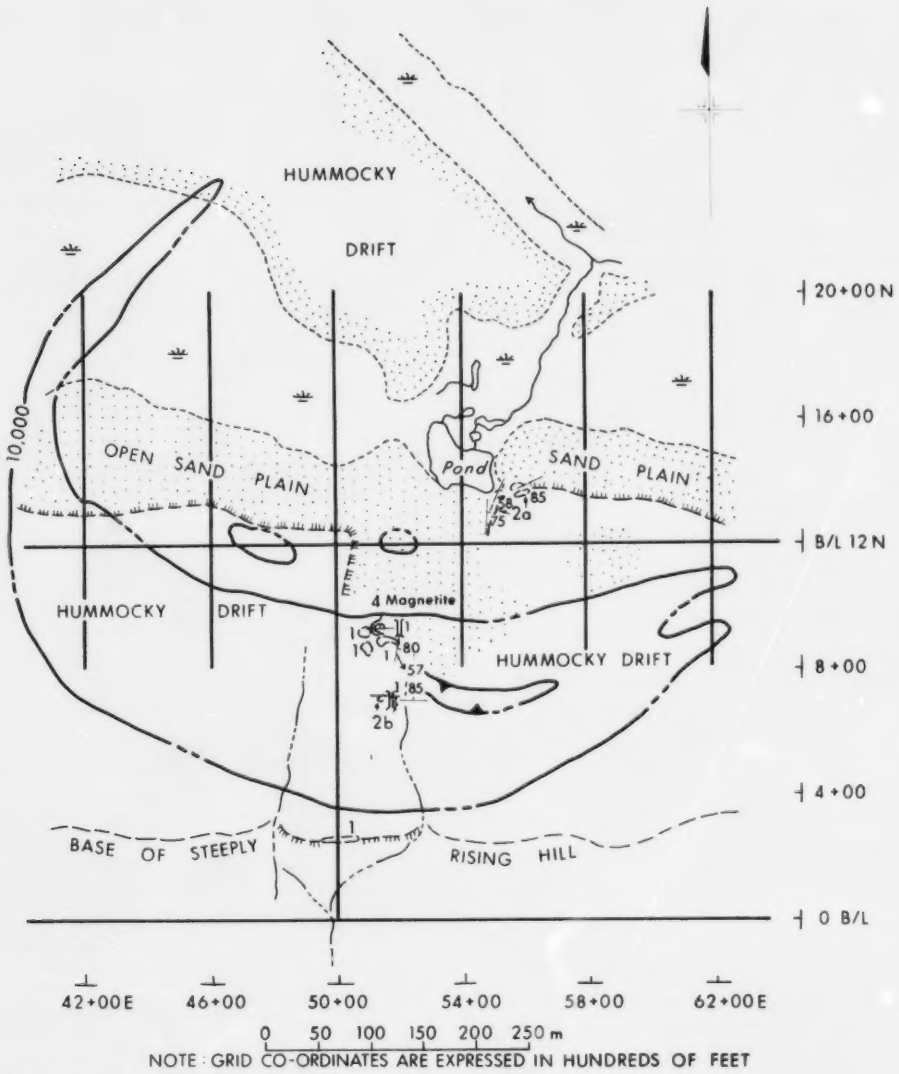
4+00SW
3
4
4A
4B
1
LEGEND
4B QUARTZITE (DISSEM Py & Mag)
4A LEAN IRON FORMATION (MOSTLY SILICATE FACIES)
4 IRON FORMATION
3 AMPHIBOLITES (MAFIC GRANULITES)
2 BIOTITE SCHIST AND GNEISS
1 GRANITIC GNEISS
0 50 100 150 200 m
NOTE: GRID COORDINATES ARE EXPRESSED IN HUNDREDS OF FEET



LEGEND

4 IRON FORMATION

2 METASEDIMENTARY ROCKS; 2a, BIOTITE GNEISS; 2b, HORNBLENDE – FELDSPAR GNEISS

1 GRANITIC GNEISS

SYMBOLS

AREA OF OUTCROP

FOLIATION (INCLINED, DIP UNKNOWN)

ESCARPMENT

SAND DEPOSITS

TRENCH OR TEST PIT

MUSKEG OR SWAMP

INTERMITTENT STREAM

PICKET LINES

10,000 GAMMA CONTOUR LINE

Figure 9. *Geology and ground magnetic anomaly, Ithingo East occurrence.*

magnetometer study (Figure 9) and by airphoto lineaments. This part of the dome plunges steeply southwest.

Geochemistry

Two sections of iron formation (15.2 and 3.0 m) exposed in trenches at the western end of the West occurrence were chip sampled. The results shown in Table 6 are for crude ore samples since concentrates were not made. The acid soluble iron content has weighted averages of 18.51 percent and 16.36 percent for samples taken from the two trenches. The highest concentrations were found in the first trench (samples 116-120) which averages 29.57 percent Fe over a distance of 7.6 m; this, however, corresponds to a pyrrhotite-rich zone. The iron content is generally too low to be of economic interest. The high silica content reflects the siliceous nature of the rock itself. Both titanium and phosphorus are present in very small quantities.

Geophysics

A ground magnetic survey was conducted on pre-cut lines spaced 120 m apart, with readings being taken at 30 m intervals (15 m intervals in areas of high magnetism). The data were plotted at 1:2400 and 1:4800 scales and contoured using a 1000 gamma contour interval. Background in the vicinity of the anomalies is generally 60 000 to 61 000 gammas, while the anomalies yielded readings greater than 4000 gammas above background.

Most areas underlain by iron formation in the West occurrence yielded a nearly constant value of 65 523±2 gammas, producing a plateau-like profile. In areas underlain predominantly by ferruginous quartzite, the profile obtained was similar to that modelled for a dipping dyke (Breiner, 1973). A magnetic depression was also noted along the footwall contact between the iron formation-ferruginous quartzites and the amphibolites. A peak was generally encountered along the hanging wall contact due to the southerly dipping attitude of the iron formation. In the East occurrence, the profile is similar to that modelled for a dipping dyke, implying a single southerly dipping horizon. The resolution of the magnetics is probably better in the East occurrence (Figure 9) because of the increased depth to the source.

In general, the ground magnetic survey was successful in locating some areas of iron formation that might otherwise have been missed. A very good correlation was observed between the magnetics and the geology.

Economic Evaluation

The Ithingo Lake iron occurrences are highly metamorphosed sedimentary iron formations classified as metataconite deposits amenable to open-pit mining methods. The granularity and grain size (average 1 mm) would make these occurrences suitable for coarse grinding and magnetic separation. A good quality ore with neglible impurities could probably be produced through concentration, although sulphur from pyrrhotite could present problems. The West occurrence is the more promising, being contained in a U-shaped southerly plunging body occupying an area approximately 600 m long by 60 m wide. The average iron content obtained from the 15.2 m section (Table 6) is, however, only 18.51 percent Fe, including iron contained in sulphides. Accepting this value as the average grade, the deposit would therefore only contain about 7 million tonnes (8 million tons). A high waste to ore ratio would be expected because of the association of unmineralized quartzite with the iron formation.

The single outcrop of iron formation in the East occurrence, when trenched, was found to be

Table 6. Summary of Analytical Results, Ithingo Lake. All Values in Weight Percent

Sample Number	*Section Sampled (m)*	*Soluble Fe*	*Si*	*Mg*	*Mn*	*Ti*	*S*	*P*	*Weighted Average Soluble Fe*
116	0-1.5	31.8	15.8	2.38	1.32	0.01	6.51	0.015	Samples
117	1.5-3.0	33.7	15.8	1.54	1.26	<0.01	12.75	0.008	116-120:
118	3.0-4.6	26.7	21.9	1.24	0.95	<0.01	9.09	0.014	29.57% Fe
119	4.6-6.1	25.4	21.1	1.54	1.21	<0.01	9.29	0.012	8.08% S
120	6.1-7.6	29.8	16.3	3.32	1.35	<0.01	3.06	0.010	
121	7.6-9.1	8.00	26.6	3.62	1.35	<0.01	0.88	0.020	Samples
122	9.1-10.7	13.2	32.8	0.27	0.08	0.01	0.33	0.010	116-125:
123	10.7-12.2	4.92	38.8	0.43	0.35	<0.01	1.17	0.009	18.51% Fe
124	12.2-13.7	4.07	38.0	1.27	0.20	<0.01	0.88	0.009	
125	13.7-15.2	3.82	42.6	0.27	0.07	<0.01	0.29	0.005	Samples
126	0-1.5	14.5	31.0	1.20	0.63	<0.01	1.68	0.023	126-127:
127	1.5-3.0	18.6	29.0	1.38	0.76	<0.01	0.88	0.014	16.36% Fe

completely enclosed within pink gneissic granite and of fairly low grade. Since this exposure is coincident with the strongest magnetic anomaly, the East occurrence would appear to have negligible potential.

In summary, the iron occurrences south of Ithingo Lake are considered uneconomic because of their low grade, small size, high waste to ore ratio and geographic remoteness.

Dot Lake

Exploration activity started prior to 1955 southwest of Dot Lake. The federal-provincial airborne magnetic survey flown in 1964 (Geological Survey of Canada, 1965b) revealed several anomalies that attracted the attention of Rio Tinto Canadian Exploration Limited. In 1968, the area was evaluated for mineralization associated with ultrabasic intrusions. The magnetic anomaly located about 1.6 km southwest of Dot Lake indicated a banded quartz-magnetite iron formation as well as basic intrusions (Assessment File 74B06-NE-0005). Base metal mineralization was discovered in quartzites several kilometres to the southwest (Pearson, 1972, 1977). After examination of this area in 1975 for its iron potential, it was concluded the occurrence was not large enough to be of economic interest.

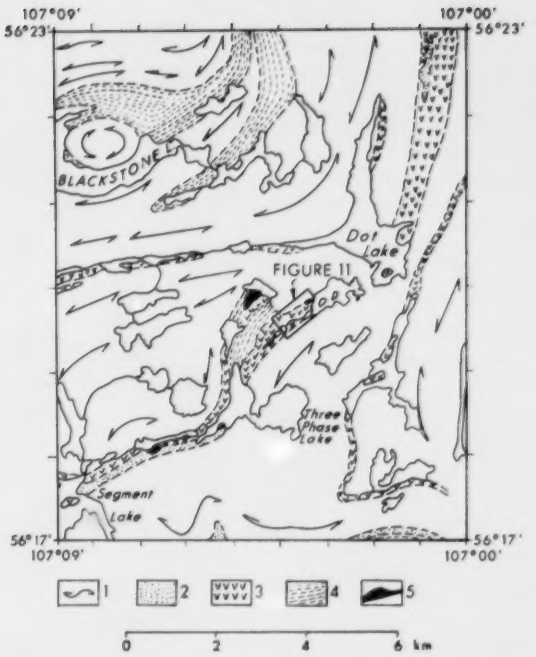


Figure 10. Generalized geology of the Dot Lake area (after Pearson, 1977). 1, granite and hypersthene-bearing granite gneiss; 2, psammites, quartzofeldspathic rocks with minor graphite, biotite and garnet; 3, mafic gneisses, amphibolites, pyribolites and ultramafic rocks; 4, metapelitic gneisses; 5, banded quartz-magnetite iron formation and associated rocks.

Geology

Dot Lake lies within the Mudjatik Domain, in an area dominated by dome-and-basin structures (Pearson and Lewry, 1974; Lewry and Sibbald, 1977). A supracrustal zone characterized by mafic granulites (hypersthene amphibolite, pyribolite, pyroxenite) and basic to ultrabasic (gabbro, hornblendite) intrusives (?) extends southwest from the south end of Dot Lake along the axis of an aeromagnetic anomaly (Figure 10). Interlayered with the mafic granulites are banded quartz-magnetite iron formation and ferruginous quartzite. The supracrustal zone is bounded by granitic gneisses. The detailed geology of the Dot Lake occurrence is shown in Figure 11.

Despite the effects of Hudsonian deformation and granulite facies metamorphism, the iron formation still shows banding, although other sedimentary structures have probably been destroyed. Five horizons of iron formation have been mapped, but some of these may be a single horizon repeated by folding. The rocks commonly strike northeast and the dip varies from 30° southeast to almost vertical. Small-scale structures indicate easterly plunging folds with southeasterly dipping, northeast-striking axial surfaces. Deflected around the basic masses, the rocks dip more steeply in these regions.

Some of the mafic granulites appear to be among the oldest supracrustal rocks present, but because of the structural complexity and the fact that both mafic granulites and iron formation are in contact with the granitic gneisses, there is some uncertainty about the stratigraphic relationships. Table 7 summarizes the rock units, but their relative ages are only tentative.

Table 7. Table of Formations[1], Dot Lake Area

Cenozoic	Recent	Lake and stream deposits, peat
	Pleistocene	Glacial deposits
		Unconformity
Aphebian		Metagabbro, hornblendite (4)
		Intrusive Contact
		Iron formation (3, 3a)
		Mafic granulites (2); includes amphibolite, and pyroxene-amphibole and hornblende-biotite gneisses
		Unconformity
Archean (Remobilized Complex)		Granitic gneisses (1)

[1]Numbers correspond to those in Figure 11.

Rock Descriptions

Granitic gneisses overlie and underlie the supracrustals along both margins of the supracrustal zone (Figure 11). They generally weather pink to rusty brown, but more mafic varieties close to the supracrustal zone are brown to brownish grey on fresh and weathered surfaces. They contain up to 15 percent biotite and 5 percent hypersthene except at the contact between the granitic gneisses and the iron formation, where they contain up to 30 percent magnetite.

The granitic gneisses are commonly coarse grained (5 mm average grain size) and are composed of feldspar, quartz and biotite, with or without hypersthene, garnet and magnetite. The gneissosity is marked by layers of biotite, 1 to 3 mm thick, alternating with leucocratic layers, commonly 1 cm thick. The granitic gneisses may be in part derived from older igneous rocks or granitized sediments.

Mafic granulites, which dominate the supracrustal zone, form a 240 to 360 m wide band and are in part interlayered with iron formation (Figure 11). The main rock type is a hornblende-bearing rock that is generally equigranular, of medium to coarse grain size, dark green to dark grey on fresh and weathered surfaces, and massive to poorly foliated. In a few places, alternating amphibole-pyroxene-rich and feldspar-rich layering, 0.2 to 2 cm thick, is well developed.

The mafic granulites are of dioritic composition and consist essentially of hornblende and plagioclase, with lesser amounts of biotite, pyroxene and magnetite. Finely disseminated pyrite is common and is responsible for splotches of limonite stain. These rocks may represent highly metamorphosed basaltic to andesitic flows or pyroclastics, although an origin from sedimentary rocks may be applicable for some.

Bands of **iron formation**, commonly 10 to 30 m wide, are interlayered with and in part gradational into the mafic granulites (Figure 11). The iron formation includes banded quartz-magnetite rocks and pyrite-pyrrhotite-magnetite-bearing quartzite. The banded iron formation is the most abundant rock type and is characterized by a rusty brown or grey to blue-grey colour on fresh and weathered surfaces and by sharply defined, alternating quartz-rich and magnetite-rich layers, commonly 0.1 to 2 cm thick (Plate 1).

The relatively pure quartz-rich layers contain minor amounts of feldspar, biotite and finely disseminated magnetite. The magnetite-rich layers are composed of 30 to 70 percent magnetite, the remainder being mainly quartz. Both quartz and magnetite are granular, with grain size ranging from 0.5 to 1 mm, but, in places, magnetite aggregates reach 2 to 3 cm across. Mobilization of the magnetite is indicated by coarse-grained masses that occupy fractures in some parts of the rock.

The sulphide-bearing quartzites commonly occur in bands 2 to 3 m wide, with some bands up to 30 m wide that can be traced for as much as 300 m along strike. They have well-defined layering (4 to 50 cm thick) and minor layers (5 to 10 cm thick) of banded quartz-magnetite iron formation. Unlike the banded variety, the sulphide iron formation is strongly iron stained. The quartzite, which is generally coarse grained, contains clear to greenish quartz, and approximately equal amounts of disseminated pyrite, pyrrhotite and magnetite (commonly 2 mm in diameter). Biotite usually forms less than 5 percent of the rock, while the opaque minerals together comprise less than 10 percent.

A body of **metagabbro**, approximately 1.6 km long and up to 180 m wide, extends from the southwest end of the area mapped to Three Phase Lake (Unit 3 in Figure 10 and Unit 4 in Figure 11). A small body of **hornblendite**, oval shaped in plan and measuring 120 by 60 m, lies 60 m northeast of the northeastern end of the metagabbro. Several smaller bodies of hornblendite, 3 to 4 m wide, occur in the mafic granulites.

The metagabbro is generally brown to rusty brown on weathered surfaces, black on fresh surfaces, massive to poorly foliated and medium to coarse grained. It contains as much as 10 percent magnetite, while the hornblendite contains little or no magnetite. The metagabbro is composed essentially of hornblende, plagioclase and magnetite. Results from three grab samples of metagabbro assayed for Fe, Ni, and Ti are listed in Table 8.

The hornblendite, dark grey to black on both fresh and weathered surfaces, is very coarse grained (5 mm average grain size) and massive. Hornblende makes up approximately 60 to 80 percent of the rock, the remainder being largely plagioclase.

The metagabbro and hornblendite are undoubtedly plutonic rocks, occurring as dykes, sills or stocks around which the supracrustals are strongly deformed.

Origin of the Iron Formation

Gross (1965, 1968) has noted that banded, cherty, iron oxide iron formations retain their bedding at higher grades of metamorphism than most other sediments. The quartz-rich and magnetite-rich layering of the Dot Lake iron formation, as well as the layering in quartzites (Subunit 3a in Figure 11),

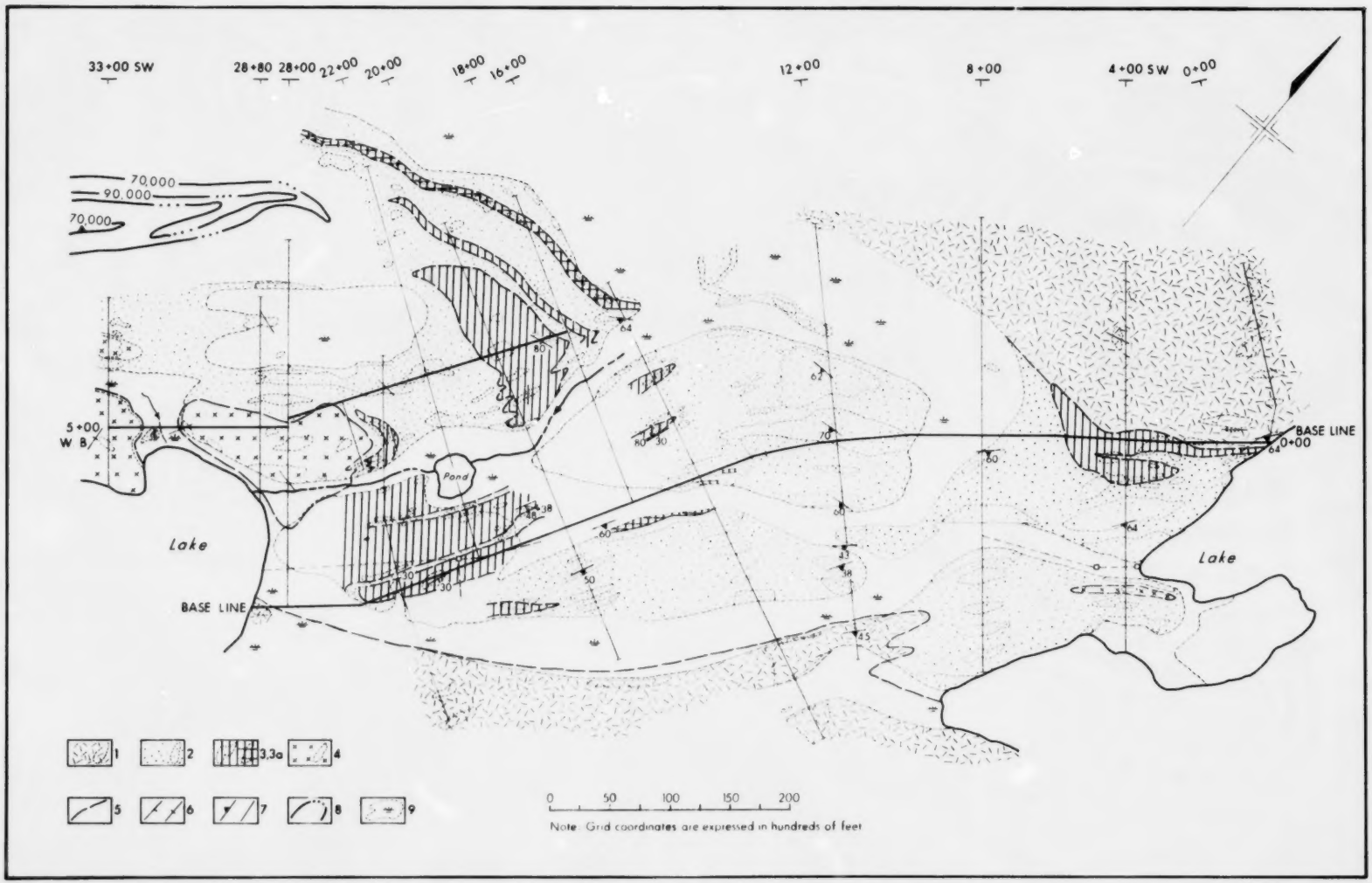


Figure 11. *Geology of the Dot Lake iron occurrence. 1, granite gneiss; 2, mafic granulites; 3, iron formation, sulphide-oxide facies and quartzite; 3a, iron formation; 4, metagabbro and hornblendite; 5, geologic contacts; 6, bedding (inclined, dip unknown); 7, gneissosity (inclined, dip unknown); 8, ground magnetic contours in unexposed area (shows continuation of iron formation to the southwest); 9, muskeg. Dashed lines in rock units 1 to 4 indicate areas of outcrop.*

undoubtedly represents bedding. The banded quartz-magnetite iron formation was probably precipitated as a cherty, iron oxide facies iron formation, whereas the pyrite-pyrrhotite-magnetite-bearing quartzite represents a transitional iron oxide/iron sulphide facies.

The supracrustal zone is dominated by mafic granulites and basic intrusives interpreted as a volcanic environment. Quartzites and garnet-biotite gneisses occur immediately northwest of the area mapped, indicating a greater sedimentary component than is revealed in the study area. The close volcanic association suggests an Algoman-type environment, but the regional distribution of iron formation in the Mudjatik Domain, although greatly disrupted, is more like that of the Superior type. Therefore, the Dot Lake iron formation cannot confidently be grouped with either type but may be transitional between the two.

Structure

Primary sedimentary and volcanic structures are not common, although bedding is preserved in the iron formations. Gneissosity and schistosity are weak due to post-tectonic crystallization. Bedding and foliations generally strike northeasterly and dip southeasterly at 30° in the southeast of the map area. The dip is much steeper (up to 70°) in the northeast.

The structure of the Dot Lake supracrustal zone is apparently dominated by migmatite lobe tectonics described by Pearson and Lewry (1974) and Lewry and Sibbald (1977) as producing essentially flat-lying, recumbent, isoclinal folds (F_1). These folds were tilted to varying degrees by the D_2 antiformal and synformal structures and subsequently refolded during the D_3 deformation into dome-and-basin patterns. Most of the larger folds are isoclinal and could be either primary F_1 folds or F_3 parasitic folds related to a D_3 antiform. These folds trend northeast, dip southeast at 45°, and have a stereographically determined plunge of 30 to 60° at an azimuth of 110°.

Small-scale folds are rare in the granitic gneisses and mafic granulites but numerous and commonly refolded in the iron formation. Many of the refolded folds seem to be unrelated to the regional structure but display characteristics similar to types 2G and 3F interference structures (Ramsay, 1967). The most common small-scale folds are similar in style and have an easterly plunge of 30 to 40°. These folds appear to be related to the larger folds. Southeast-trending open warps, undoubtedly of F_2 age, are common and have a southeasterly plunge of 30° along near-vertical axial surfaces.

The aeromagnetic anomaly has been caused by the 'stacking' of closely spaced isoclinal folds of relatively thin iron formation layers.

Geochemistry

Nine grab samples from this map area were analyzed. The granitic gneiss sample (Table 8, sample 110), collected less than 1 m from the contact with the iron formation, contains appreciable magnetite and is essentially geochemically similar to the iron formation; this suggests that the gneiss may have been partially derived from the iron formation. Obvious differences in composition do exist, however, particularly in the contents of Al and, to a lesser extent, Mg and Ti.

The five iron formation samples (Table 8, samples 111 to 115) average 32.8 percent Fe and have very low quantities of P, S, Ti and Mg. A concentrate made from this iron formation would probably be ideal for Bessemer-quality ore.

Three magnetite-bearing metagabbro samples (Table 8, samples 131 to 133), assayed for Ni, Ti and acid-soluble Fe, contain negligible concentrations of the two trace elements.

Table 8. Summary of Analytical Results, Dot Lake. All Values in Weight Percent

Sample Number	Soluble Fe	Si	Al	Ca	Mg	Mn	S	P	Ti	Ni	LOI[1] @ 105°C	LOI @ 21°C
110	19.1	24.5	4.3	1.46	1.78	0.08	0.09	0.04	0.22		0.26	0.17
111	35.4	22.4	0.2	1.18	0.81	0.03	0.05	0.03	<0.01		0.07	0.06
112	33.5	24.2	0.1	1.14	0.45	0.03	0.03	0.06	<0.01		0.16	<0.01
113	36.4	22.1	0.2	1.84	0.15	0.06	0.02	0.08	<0.01		0.14	<0.01
114	23.9	30.2	0.1	0.57	1.18	0.08	0.05	0.03	<0.01		0.22	0.13
115	34.9	21.8	0.1	1.86	1.16	0.05	0.01	0.07	<0.01		0.16	<0.01
Arithmetic Average 111-115	32.8	24.2	0.16	1.32	0.75	0.05	0.03	0.05	<0.01		0.15	<0.02
131	4.82								0.90	<0.01		
132	10.16								0.34	0.13		
133	12.0								0.36	0.11		

[1]Loss-on-Ignition

Geophysics

Readings were taken with the fluxgate magnetometer at 15 m (50 foot) intervals and at 7.5 m (25 foot) intervals in areas of high magnetic intensity on pre-cut lines spaced 60 and 120 m (200 and 400 feet) apart. For simplification the readings were divided by 10, plotted at a scale of 1:2400 and contoured using a 1000 gamma contour interval.

Background values for nonmagnetic rocks are generally 60 000 ± 2000 gammas; magnetic rocks normally have a background of 70 000 to 80 000 gammas. The 7000 gamma contour more or less delineates areas underlain by iron formation. In several places, particularly in the southwest corner where bedrock exposure is poor, strong magnetic anomalies along strike from areas of exposed iron formation may reflect iron formation buried beneath the surficial deposits. The larger mass of hornblendite shows up as a magnetic depression.

Economic Evaluation

The Dot Lake iron occurrence is classified as a metataconite deposit. Its coarse grain size and granoblastic texture make the ore suitable for coarse grinding and magnetic separation. The deposit, although relatively pure, is too small to warrant further attention at this time.

Two small, roughly oval-shaped zones of iron formation in the southwestern part of the grid are estimated to contain about 14 to 16 million tonnes (15 to 18 million tons) of ore grading 30 percent Fe. The expected dilution factor of about 40 percent would make the actual reserves much lower. The remoteness of the area and high transportation costs are other unfavourable factors.

Fish Hook Bay

Iron formation was reported in this area in 1893 by Tyrrell and Dowling (1896) and again in 1914 and 1916 by Alcock (1936); however, no interest was shown in these occurrences until 1921 when several claims were staked. Allan and Cameron (1923) concluded that there were no deposits of "iron ore" in the Fish Hook Bay area. Similar conclusions were reported by Christie (1953). From the early 1940s to the present, the area around Fish Hook Bay has been held by Eldorado Nuclear Limited, primarily as a uranium property.

In view of the lower grades of iron deposits currently being mined, the author carried out a brief examination and sampling of the iron formation in and around Fish Hook Bay, and the ferruginous quartzite breccias south of Iron Cove.

Geology

The Fish Hook Bay area is underlain by Tazin Group metasedimentary rocks of Tremblay's (1972) Murmac Bay Formation (Figure 12; Figure 13, back pocket). A thick sequence of quartzites, dolomitic and siliceous iron formation, dolomite and argillaceous rocks were intruded by ultrabasic rocks, diabase dykes and granite. Elsewhere (north and west), the Murmac Bay Formation contains thick sequences of garnetiferous pelites and amphibolites derived from sedimentary and volcanic rocks (Christie, 1953; Tremblay, 1972). The stratigraphy of the area is shown in Figure 14.

The Fish Hook Bay area forms part of the eastern limb of a large southwesterly plunging synclinorium centred about Goldfields. Mineral parageneses indicate middle amphibolite facies conditions, but there is evidence of retrograde metamorphism in the upper greenschist-lowest amphibolite facies related to a period of intense fracturing, brecciation and mylonitization. Extensive alteration is also prevalent.

Rock Descriptions

Rocks of similar composition occur at various stratigraphic levels. Only the major rock types are described here.

Quartzites, by far the most abundant rocks in the area, reach a maximum thickness of at least 1200 m near Lake Athabasca and thin northward, where they are interlayered with metapelites, metagreywackes and carbonates. The quartzites consist of granular, massive and brecciated varieties accompanied by conglomeratic, argillaceous and dolomitic lenses. The rocks are fine to coarse grained, have variable bedding thicknesses (1 cm to several metres), and are white, light grey, green and light brown on fresh and weathered surfaces. Channel scours and cross-beds are present (Plate 2) but not abundant. The quartzite breccias are composed of angular white quartz fragments, commonly 2 to 5 cm long, although some are as much as 10 cm long. They are commonly cemented by either silica or hematite. Intergranular cavities are lined with tiny quartz crystals coated with specular hematite. Larger crystals of specular hematite also occur in these cavities. Brecciation is widespread but irregularly distributed, and is probably related to fractures (Christie, 1953). Tremblay (1972) believes that some of the breccias may be primary clastic features, while others may be cataclastic.

Thin pebbly conglomeratic lenses, generally less than 1 m thick, consist of white quartz pebbles averaging 1 to 2 cm in diameter. Argillaceous rocks, which contain more biotite and hornblende, are characteristically dark brownish grey. Dolomitic

beds weather readily and are commonly a brownish colour, in contrast to the calcareous quartzites which tend to be pale green due to diopside.

The contact between the basal quartzite and the overlying sediments on Shirley Peninsula is generally abrupt (Plate 3). In several places a poorly exposed breccia zone, 5 cm thick, occurs at the contact between the quartzite and iron formation; this is either an intraformational or a tectonic breccia.

The conglomerates, channel scours and cross-bedding attest to the high energy environment in which the quartzites were deposited.

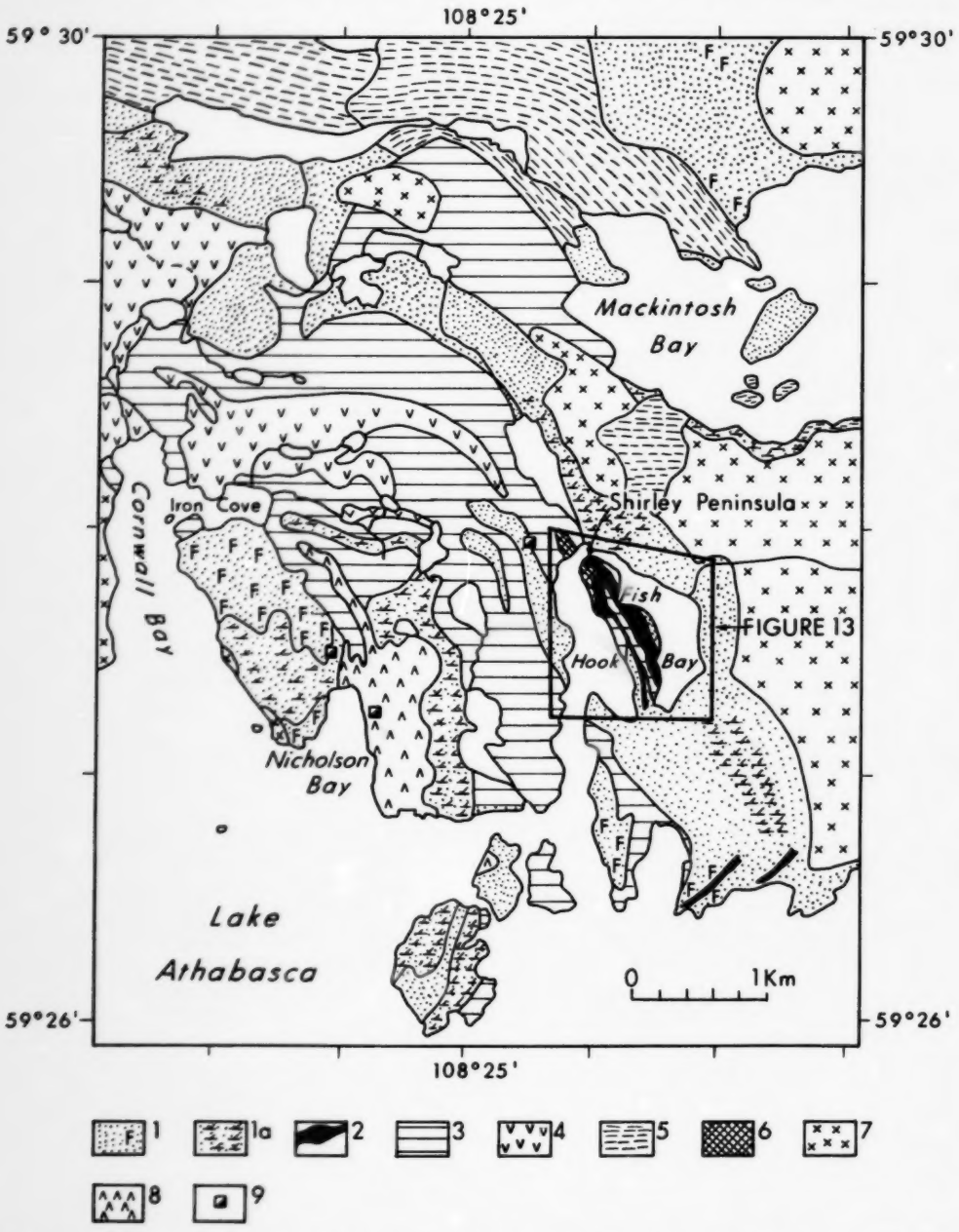


Figure 12. Generalized geology of the Fish Hook Bay area, showing distribution of iron formation and ferruginous quartzites (modified from Christie, 1953). 1, quartzites (F, ferruginous quartzites and quartzite breccias); 1a, quartzite with minor amounts of dolomitic material; 2, quartz-hematite and/or quartz-magnetite iron formation, including some iron silicate facies iron formation; 3, dolomite and dolomitic quartzites; 4, amphibolites of sedimentary origin; 5, metapelitic rocks; 6, pyroxenite; 7, granite; 8, amphibolites of igneous origin; 9, abandoned mine shaft.

Two 15 m thick bands of **iron formation** on Shirley Peninsula (Figure 13) can be traced along strike for 1300 m. Iron formation is also found on the headland about 1 km east of the mouth of Fish Hook Bay (Figure 12), although its thickness and length are not accurately known. The iron formation is basically fine grained and consists of alternating silica-rich and hematite-rich layers that vary in thickness from 0.5 to 5 cm and 0.1 to 1 cm, respectively (Plate 4).

Two different associations exist. The lower iron formation on Shirley Peninsula is in part calcareous, interlayered with dolomites, and has a widespread hematite staining. The iron minerals are mainly earthy and specular hematite with minor magnetite, although pyrite and jasper are also present. The upper and younger iron formation is more siliceous, has a blue to bluish grey colour caused by specular hematite and magnetite, and contains iron silicate minerals. The iron formation on the headland to the southeast is similar to the upper band exposed on Shirley Peninsula.

In thin section, the earthy and specular hematite occurs interstitial to quartz as minute granules (<<0.1 mm), anhedral masses and platy grains (up to 0.2 mm long). In the upper iron formation, it is also interstitial to the iron silicate minerals. Pyrite may be present in close association with hematite in the lower iron formation; in the upper iron formation, specular hematite is intimately mixed with magnetite. Both earthy and specular hematite occur as fracture fillings and as thin coats on many grains. This is particularly well displayed in the ferruginous dolomites. Stockwork veins of coarse platy specularite crystals, up to 1 mm in diameter, are abundant and commonly accompanied by carbonate (calcite and dolomite). In places, dolomite and iron silicate minerals are altered to earthy and/or specular hematite. In one thin section (7615-H245B), hematite is accompanied by sericite, probably produced by the alteration of biotite.

On Shirley Peninsula, **dolomites** are interlayered with quartzites and iron formation in layers that vary from about 1 cm to 30 m in thickness. Cross-bedding is a common feature of some layers (Plate 5). A thicker section of dolomite west of Fish Hook Bay was not fully examined. The dolomite is tan to chocolate brown with a sandy texture on weathered surfaces; on fresh surfaces, the rock is white and fine to coarsely crystalline. The dolomite is thinly to massively layered and locally cross-bedded. Possible bedding planes are marked by green to black weathering, more resistant grains of diopside which may have been derived from chert nodules or layers. In places, diopside is very abundant and reflects a more siliceous composition. In a ferruginous variety characterized by bright red weathering, dolomite grains are coated with red earthy hematite. Specularite is also abundant (Plate 6). The red ferruginous dolomites grade both laterally and vertically into brown dolomite.

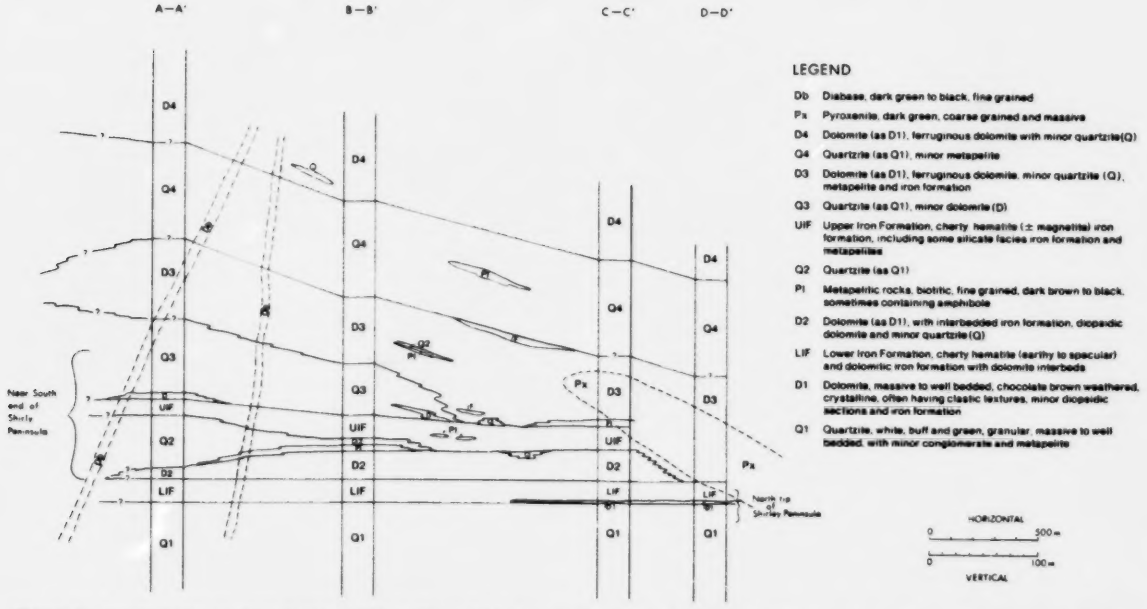

A–A'
B–B'
C–C'
D–D'
LEGEND
Db Diabase, dark green to black, fine grained
Px Pyroxenite, dark green, coarse grained and massive
D4 Dolomite (as D1), ferruginous dolomite with minor quartzite(Q)
Q4 Quartzite (as Q1), minor metapelite
D3 Dolomite (as D1), ferruginous dolomite, minor quartzite (Q), metapelite and iron formation
Q3 Quartzite (as Q1), minor dolomite (D)
UIF Upper Iron Formation, cherty hematite (± magnetite) iron formation, including some silicate facies iron formation and metapelites
Q2 Quartzite (as Q1)
Pl Metapelitic rocks, biotitic, fine grained, dark brown to black, sometimes containing amphibole
D2 Dolomite (as D1), with interbedded iron formation, diopsidic dolomite and minor quartzite (Q)
LIF Lower Iron Formation, cherty hematite (earthy to specular) and dolomitic iron formation with dolomite interbeds
D1 Dolomite, massive to well bedded, chocolate brown weathered, crystalline, often having clastic textures, minor diopsidic sections and iron formation
Q1 Quartzite, white, buff and green, granular, massive to well bedded, with minor conglomerate and metapelite
Near South end of Shirley Peninsula
North tip of Shirley Peninsula
HORIZONTAL
0 500 m
0 100 m
VERTICAL

Figure 14. *Stratigraphic sections A-A' to D-D' (see Figure 13 for locations), Fish Hook Bay area. Thicknesses of Q_3 and D_4 are approximate. Datum level taken as contact between Q_1 and LIF.*

Argillaceous rocks, relatively unimportant, occur as small lenses, most commonly associated with the quartzites. They are dark grey on fresh and weathered surfaces and generally fine grained.

Dykes and/or sills of **pyroxenite and diabase** intrude the previously described rocks. The pyroxenite, a dark green massive rock, is strongly altered to talc and chlorite, and is iron stained due to the presence of specularite and magnetite. It mainly occurs at the northeast end of Shirley Peninsula, while the diabase dykes are found at the southern end. The diabase is typically dark green, massive and fine to medium grained.

Origin and Environment of Deposition of the Iron Formation

The sedimentary rocks of the Murmac Bay Formation are believed to represent an alternating sequence of clastic and chemical sediments interbedded with tuffs and pyroclastics. The general distribution of the sediments seems to indicate an original shoreline to the south and east. The amphibolites which occur north and west of Fish Hook Bay appear to be of both sedimentary and volcanic origin, and were probably deposited in a deepening marine basin or a flanking volcanic arc (Christie, 1953; Tremblay, 1972). Tremblay suggsts that the deformational style shown by the members of the Murmac Bay Formation is more typical of platform deposition, whereas possible equivalents of the Murmac Bay Formation north of the St. Louis and Black Bay Faults show features more typical of geosynclinal deformation.

The conglomeratic varieties, cross-beds and channel scours associated with the quartzites indicate high energy conditions. Some periods of quiescence, however, must have occurred to allow the deposition of the shale and chert lenses. The narrow breccia zone that locally separates the quartzites and chemical sediments may indicate a short period of erosion. Cross-bedding in some of the dolomites may indicate some redistribution of earlier formed sediment. The presence of iron oxides in these chemical sediments suggests oxidizing conditions. However, the presence of iron sulphides in some layers may suggest a change towards reducing conditions. The major carbonate cycle was followed by the deposition of relatively pure, cherty, oxide facies iron formation, then clastic sedimentation of sandstones and shales, and finally another period of carbonate sedimentation.

The Fish Hook Bay sedimentary sequence is comparable to carbonate sedimentary cycles in the Transvaal Supergroup of South Africa, where banded iron formation is thought "to be an end member in a series of chemical and sedimentary cycles ... caused [by] a partial restriction between the iron formation environment and the open ocean" (Button, 1976, p.193). The Murmac Bay Formation undoubtedly represents platform sediments that were deposited in a near-shore and, perhaps at times, lagoonal environment.

The iron formation and its associated rocks have many of the characteristics of a Superior-type iron formation. Volcanic rocks, although not evident in the immediate area, occur elsewhere in the same stratigraphic succession (Christie, 1953; Tremblay, 1972). One obvious difference between these iron formations and the Superior type is their short lenticular shape. Since this is the only characteristic they have in common with the Algoma type, there seems to be sufficient evidence to classify them as Superior-type iron formations. The iron formation on the north shore of Lake Athabasca may represent only a remnant of a much larger, more continuous platform succession.

Structure

The Fish Hook Bay area lies on the eastern limb of a southwesterly plunging synclinorium centred in the Goldfields area (Christie, 1953). Immediately adjacent to Fish Hook Bay, the rocks strike north to north-northwest and generally dip 30 to 45° west, except where small-scale folds and large parasitic folds related to the synclinorium have complicated an otherwise simple structure. Bedding is the dominant planar fabric, although a poorly to well-developed metamorphic foliation lies essentially parallel to bedding.

Folds on the east side of Shirley Peninsula and on the northeast side of Fish Hook Bay are open, undulating and southerly to southwesterly plunging, although some plunge at low angles to the northeast. These folds indicate a large regional parasitic fold in the limb of the Goldfields synclinorium, although fault-related drag folding, due to an unproven fault passing through the east arm of Fish Hook Bay, cannot be ruled out.

Small-scale faults and shears with up to 1.2 m of displacement were observed, but no major faults were detected. A fault may extend beneath the east arm of Fish Hook Bay and continue northwestward along the Fish Hook Valley (Assessment File 74N08-NW-0079). A breccia zone was indicated by diamond-drilling, but Tremblay (1972) pointed out that brecciation does not necessarily imply fault movement.

Metamorphism and Alteration

The rocks in the Fish Hook Bay area have been affected by low to middle amphibolite facies

metamorphism. Rocks south of the St. Louis Fault lie almost entirely within the almandine-amphibolite facies (Tremblay, 1972). Diagnostic mineral assemblages are not present because they "have been destroyed or obscured later by retrogressive effects related to dynamic metamorphism and late phases of granitization, such as metasomatic replacement and hydrothermal alteration" (Tremblay, 1972, p.136).

Alteration, widespread in the Beaverlodge area, consists of hematization, chloritization, epidotization, silicification, carbonitization and albitization (Tremblay, 1972). In the Fish Hook Bay area, hematization, silicification and carbonatization are common. Most of the hematite mineralization in the iron formation is primary iron oxide; however, a considerable degree of dispersion has taken place. Hematite of secondary origin occupies fractures, coats mineral grains and has replaced minerals such as dolomite and biotite. Specularite can be found in some of the intensely brecciated and fractured rocks. Hematite is the principal cementing material in some breccias, but silica is more common. Silica migration is indicated by veinlets and veins of white quartz, the presence of quartz crystals in many breccias, and silica cement. Veinlets or vuggy seams of dolomite crystals and veins of calcite also occur.

Geochemistry

Ferruginous dolomite and iron formation around Fish Hook Bay were sampled by Allan and Cameron (1923). Their results (Table 9) show that the ferruginous dolomites contain a metallic iron equivalent ranging from 3.43 to 7.98 percent, whereas the iron formation contains 16.03 to 38.22 percent. Lime and magnesia are high in the dolomites and almost nonexistent in the iron formation. Both the dolomites and iron formation contain phosphorus and sulphur in amounts acceptable for Bessemer-quality ore (Table 3).

An additional 350 channel, chip and composite chip samples were collected in the Fish Hook Bay area. Channel samples were collected at 0.3 m intervals near the north end of Shirley Peninsula. Chip samples were obtained at 0.3 m spacings along the east-west section of shoreline on the east side of Shirley Peninsula. Composite chip samples, each representing a 1.5 m section, were collected from the headland area east of the mouth of Fish Hook Bay and in the area south of Iron Cove (Figure 12). All samples were crushed and sieved, and the -80 mesh fraction analyzed for acid-soluble iron at the University of Regina. Every tenth sample was rerun for total Fe_2O_3, as well as for most major oxides, sulphur and moisture content.

The analytical results are presented in Table 10. For comparable widths, the results obtained by Allan and Cameron (1923) tend to indicate higher concentrations of iron (Table 9). Several possible explanations for the discrepancy are:

1) As revealed by the present work, the grade changes rapidly along strike due to lenses of dolomite in the lower iron formation, and to variation in the content of quartz and iron silicate minerals in the upper iron formation.
2) Analytical techniques were considerably different in 1922.
3) Analytical errors in the present study.

Table 11 summarizes whole rock and partial whole rock analyses of 35 samples. In general, P_2O_5, TiO_2, S and MnO are present in quantities acceptable for a Bessemer-quality ore; however, P_2O_5 and MnO are noticeably higher in the ferruginous dolomites.

Although the Fish Hook Bay iron formations are essentially Bessemer-quality ore, the average grade is subeconomic. The iron formation has a composition similar to that of the Superior type (Table 3) and tends to be transitional between the average iron oxide and iron silicate facies (Table 3) of iron formations.

Table 9. Summary of Analytical Results, Fish Hook Bay (Allan and Cameron, 1923). All Values in Weight Percent

Sample Number	*Sample Type*	*Representative Width (feet)*	*Iron Oxide*	*Metallic Iron Equivalent*	*SiO_2*	*Al_2O_3*	*CaO*	*MgO*	*P_2O_5*	*S*	*LOI[1]*	
A 1	Chip	20	6.04	4.22	1.28	0.38	28.56	20.06			43.08	Ferruginous Dolomite
A 2	Grab	Same location as A 1	10.02	7.01	0.51	0.10	26.41	19.38	0.027	0.049	43.40	
A 3	Chip	40	11.40	7.98	14.82	0.28	23.02	15.02			35.01	
A 4	Chip	30	4.90	3.43	0.96	0.00	29.21	19.12			45.20	
A 5	Grab	Same location as A 4	9.80	6.86	0.52	0.09	27.01	17.00			45.31	
A 6	Grab		43.40	30.38	55.80	0.15	0.00	0.00	0.018	0.052	0.50	Siliceous Iron Formation
A 7	Chip	25	22.90	16.03	59.10	0.30	4.40	3.94			8.60	
A 8	Grab	Same location as A 7	17.30	12.11	60.40	0.08	8.51	4.80	0.049	0.060	8.40	
A 9	Chip	35	48.61	34.02	49.82	0.07	0.00	0.00	0.016	0.060	1.01	
A 10	Grab	Same location as A 9	54.60	38.22	44.24	0.19	0.00	0.00	0.014	0.050	0.90	
A 11	Grab		42.08	29.45	55.76	0.60	0.00	0.12	0.021	0.041	0.90	
A 12	Chip	30	44.90	31.43	50.80	3.10	0.00	0.00	0.031	0.021	0.90	

[1]Loss-on-ignition

Table 10. Summary of Analytical Results, Fish Hook Bay. All Values in Weight Percent

Sample Number(s)	Location	Type	Length (m)	Soluble Fe (percent)	Rock Unit
H238	SE shore, Shirley Peninsula	Grab		4.6	
H240	"	"		7.0	
H245-H249	E-W shoreline, E side of Shirley Peninsula	Chip	1.5	7.16	
H250-H257	"	"	2.4	14.65	
H258-H268	"	"	3.3	20.49	Lower I.F.[1]
H269-H274	"	"	1.8	13.91	
H275-H283	"	"	2.7	19.57	
H284-H305	"	"	6.6	16.61	
H307-H330	N of right-angle corner, E-W shoreline, E side of Shirley Peninsula	"	7.5	20.16	
H331-H391	NE shoreline, Shirley Peninsula	Channel	18.3	17.58	
H392-H430	Section inland from previous section	"	11.7	18.96	Upper I.F.
H431	Iron Cove area	Grab		5.4	
H432	"	"		1.2	
H433-H437	"	Composite Chip	7.2	1.24	Ferruginous Quartzite
H438-H440	"	"	4.5	4.0	Breccia
H441-H450	"	"	15.0	3.83	
H451-H466	"	"	24.0	3.80	
B220	N tip of Shirley Peninsula	Channel	0.3	15.0	Lower I.F.
B221-B223	"	"	0.9	15.16	
B224	"	"	0.3	7.2	Upper I.F.
B225-B229	"	"	0.9	15.46	
B230-B238	"	"	3.3	17.62	
B239-B241	"	"	0.9	20.03	Lower I.F.
B242-B248	"	"	2.1	22.60	
B250-B258	"	"	2.7	24.37	Upper I.F.
B260-B307	Section going inland from NE shore of Shirley Peninsula	"	14.7	15.75	Lower I.F.
B309-B315	W side of Shirley Peninsula	"	2.1	9.18	Ferruginous Dolomite
B316-B325	"	"	3.0	2.65	
B326-B327	Headland area, E of Fish Hook Bay	Composite Chip	3.0	4.7	Red Quartzite
B328-B329	"	"	3.0	12.9	
B330	"	"	1.5	14.1	Qtz breccia
B331-B333	"	"	4.5	19.8	I.F.
B334-B338	"	"	7.5	12.08	
B339	"	"	1.5	13.0	Ferruginous Quartzite
B340-B346	"	"	10.5	13.98	
B348	"	Grab		6.7	
Weighted Averages:	Lower I.F.			17.29	
	Upper I.F.			19.47	
	Ferruginous dolomite			5.35	
	Headland ferruginous quartzite, breccia and I.F.			13.33	
	Iron Cove ferruginous breccia			3.45	

[1]I.F. = Iron Formation

Table 11. Summary of Whole Rock Analyses[1], Fish Hook Bay

	Lower I.F. (17)	*Upper I.F. (5)*	*Ferruginous Dolomite (9)*	*Headland I.F. (2)*	*Iron Cove Quartz Breccia (2)*
SiO_2	56.12	51.68	36.02	81.2	98.8
Al_2O_3	1.10	0.36	0.50	1.5	0.11
Fe_2O_3	22.97	33.06	17.14	14.1	2.4
MgO	6.58	4.8	21.28	1.0	0.44
CaO	0.84	0.47	13.96	0.1	0.11
K_2O	ND	ND	ND	ND	-
TiO_2	0.04	tr	tr	0.1	tr
P_2O_5	0.03	tr	1.17	ND	ND
MnO	0.07	0.08	0.63	0.06	0.15
Na_2O	0.29	0.35	0.45	0.54	-
H_2O^+	1.72	0.59	1.69	1.03	-
H_2O^-	0.47	0.37	0.34	0.84	-
S	0.03	tr	tr	-	tr
Totals	90.26	91.76	93.18	100.38	100.01

[1]Average values in percent; number of samples in brackets
ND = not detected
tr = trace
- = not analyzed

Economic Considerations

The Fish Hook Bay iron formations, classified as metataconite deposits, would undoubtedly require rather fine grinding to liberate much of the iron oxides. Assuming an average thickness of 12 m (40 feet) and a strike length of 900 m (3000 feet) for each iron formation unit and a maximum mining depth of 150 m (500 feet), the deposit would only contain about 14 million tonnes (16 million tons). Although the ore could yield a Bessemer-quality concentrate, the deposit is subeconomic because it grades less than 20 percent Fe and is geographically remote from potential markets.

Spence Lake

During the search for sphalerite-galena mineralization along the 'Wollaston fold belt' in the 1960s (Pyke and Partridge, 1967), magnetite-bearing argillite was noted in the Spence Lake area by Falconbridge Nickel Mines Limited (Karup-Møller, 1970). Although it was suspected that the argillite extended for a considerable distance along strike, these magnetite occurrences were dismissed at the time as being uneconomic. In 1969, drilling by Great Plains Development Company of Canada Limited northeast of Spence Lake indicated a 16 m thick magnetite zone, apparently along strike from the earlier Falconbridge find (Assessment File 64E11-NE-0016). During reconnaissance mapping of the Compulsion Bay area, Wollaston Lake by the Saskatchewan Geological Survey (Lewry, 1977), samples of iron-rich rocks collected from the area west of Spence Lake were identified as oxide-silicate and silicate facies iron formation (Coombe, 1978). Coombe re-examined the Spence Lake area in 1978 while mapping the Courtenay-Cairns Lakes belt.

Geology

Spence Lake lies within a lithostructural unit referred to as the Compulsion River fold belt (Pyke and Partridge, 1967; Karup-Møller, 1970) or the Courtenay-Cairns Lake fold belt (Scott, 1970; Lewry, 1977), in the Wollaston Domain. Wollaston Group metasediments in this belt (Ray, 1975; Gilboy, 1975) consist of a lower arkose interlayered with mafic volcanics, overlain by quartzites, slates, calcareous argillite, iron formation and arkose (Coombe, 1977, 1978). The rocks occur in a northeast-trending synclinorium bounded to the northwest and southeast by Archean granitic basement (Figure 15).

The area is only mildly deformed relative to the majority of the Wollaston Domain and the metamorphic grade is relatively low (upper greenschist to lower amphibolite facies). Bedding and sedimentary structures are preserved. According to Coombe (1977, p.86) "'way-up' structures indicate (i) a general fining of lithotypes towards the northwest and (ii) a change in character from terrestrial/shallow marine to calcareous marine sedimentation". The stratigraphy along a 35 km section of the synclinorium is shown in Figure 16.

Rock Descriptions

The following rock descriptions are taken from Coombe (1977, 1978), Scott (1970) and Lewry (1977).

The **Archean basement** in this area consists predominantly of granitic rocks. To the northwest, the Johnson River granite is characterized by coarse-grained, pink- to red-weathering, well-foliated or -lineated biotitic granite gneiss. The southeastern granitic rocks, which form part of the Peter Lake Complex[1] (Ray, 1976), consist of intensely foliated, fine- to coarse-grained, generally pink-weathering biotite-hornblende monzonite and granite. In places, these rocks appear to be gradational to the lower arkose unit and contain amphibolite xenoliths. Elsewhere, irregular bodies of medium- to coarse-grained metadiorite and metagabbro are present.

The **lower meta-arkose** occupies the southeastern edge of the fold belt. Pink to cream coloured arkoses with cross-bedded and graded scour-and-fill facies are interlayered with boulder and breccia

[1]Originally termed the Northern Intrusive Complex, following Lewry (1976).

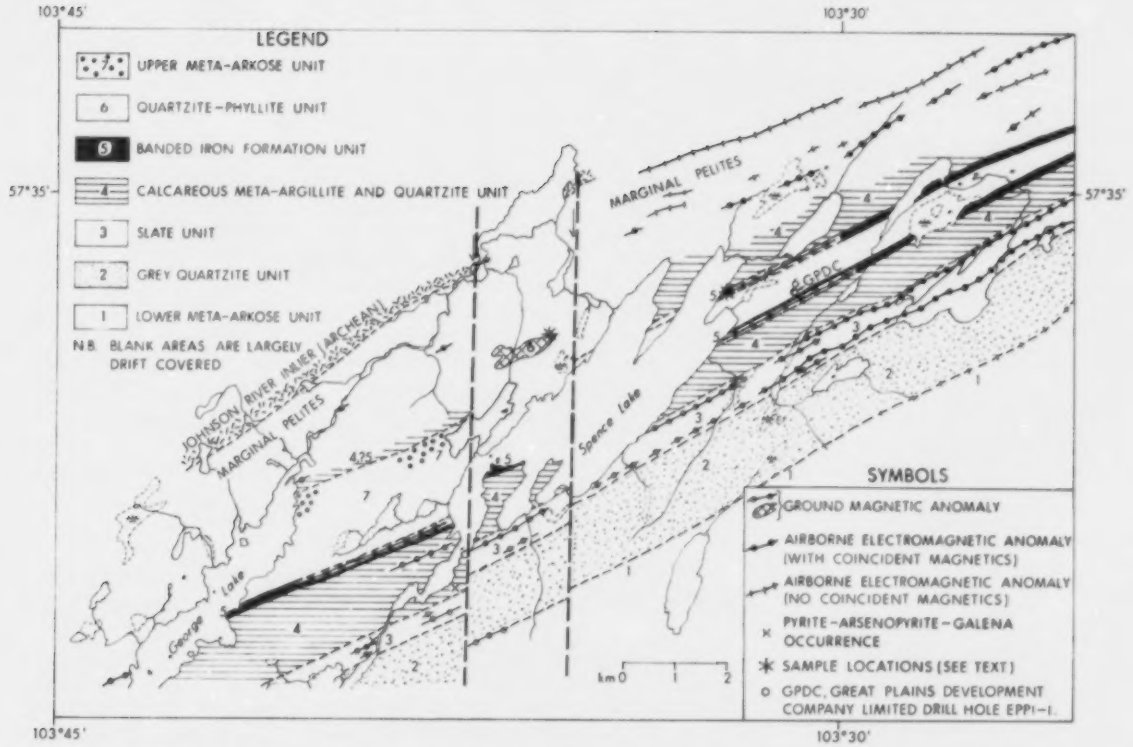


Figure 15. *Generalized geology of the Spence Lake area (from Coombe, 1978).*

conglomerate, all containing accessory magnetite and ilmenite. The conglomerates are poorly sorted and polymictic. The clasts comprise whitish-grey feldspathic quartzite, and some vein quartz and granite. Pebble lenses contain dominantly quartz and feldspar clasts. In the uppermost 600 m, the unit consists of massive or thinly bedded pink glassy quartzites, feldspathic quartzites, a distinctive porphyroblastic andalusite-biotite (after staurolite) quartz-sericite schist, meta-argillite and grey quartzite.

The meta-arkose contains at least two amphibolite horizons of volcanic origin. The lower amphibolite is heterogeneous and contains epidote lenses and sheets, and pelitic intercalations. The upper amphibolite is more homogeneous, massive, amygdaloidal or podiform and lacks pelitic interlayers. Both amphibolites have a strong magnetic signature.

The northeasterly thickening (up to 1500 m) **grey quartzite** unit is characterized by an absence of pink arkose and by the presence of sulphides, particularly sphalerite and galena, in its upper portion (Karup-Møller, 1970; Karup-Møller and Brummer, 1970). A black chiastolitic slaty argillite, becoming graphitic and containing iron sulphide towards its top, forms the base to the unit. It is overlain by a variety of grey to white quartzites and feldspathic quartzites, thinly-bedded grey pyrrhotite-bearing biotitic quartzites with scour-and-fill structures, and intercalations of meta-argillite. The upper 500 m is not exposed in the area but is known from diamond drilling (Karup-Møller, 1970) to consist of grey to white feldspathic quartzite. The zinc-lead mineralization in this uppermost unit has been described elsewhere (Karup-Møller, 1970; Karup-Møller and Brummer, 1970; Scott, 1970; Harper, 1975a; Coombe, 1977).

The **slate** unit is not exposed in the Spence Lake area but has been traced from the George Lake area by ground magnetics. It is represented by frost-heaved boulders at the southwest end of Spence Lake. The slate is 500 m thick in the George Lake area and thins both to the southwest and northeast. It consists of dark grey to black slates and slaty meta-argillites containing blebs and fracture-fillings of pyrite, pyrrhotite and locally arsenopyrite.

The **calcareous meta-argillite and quartzite** unit consists of fine-grained, light brown to cream, massive to laminated meta-argillites with thin green tremolitic siliceous interbeds at the base. These grade upwards into light green tremolitic quartzites, "massive, white to brown, 'igneous textured' tremolite-diopside (scapolite) calc-silicates"

(Coombe, 1978, p.94), striped purple-green marly rocks and thin brown carbonates (commonly displaying clastic textures).

The **banded iron formation**, which is laterally persistent and averages 100 m in thickness, consists of a lower banded garnetiferous pelite unit and the upper oxide and silicate facies iron formation. The fine-grained garnetiferous pelite is dark grey, phyllitic to schistose, and contains alternating siliceous garnet-poor and amphibole-biotite-bearing garnet-rich bands, 1 to 10 cm thick. Idioblastic garnets, typically 3 to 4 mm in diameter and deep pinkish red in colour, form 60 to 70 percent of these rocks. The lower part of the unit is characterized by "medium-grained equigranular ovoid quartzite lenticles up to 10 cm long which are mainly restricted to, and comprise up to 30 percent of, the siliceous layers" (Coombe, 1978, p.94). The lenticles may represent boudinaged sandy beds which in places are rotated and elongated parallel to fold axes.

The iron formation contains both silicate and oxide facies, as well as transitional varieties. "The silicate facies is well layered on a 2 to 10 cm scale with alternating pink-cream, light green and dark green bands" composed of "garnet with tremolite/actinolite, hornblende, quartz, and/or calcite in places. Up to 5 percent magnetite occurs near the contact with the oxide facies" (Coombe, 1978, p.94). The oxide facies rocks, which overlie the silicate facies, have an exposed thickness of about 20 m. They consist of alternating 1 cm thick, black, magnetite-rich and light grey to white, cherty, magnetite-poor bands and thin intercalations of silicate facies. "Along the northeast shore of Spence Lake, the oxide facies is ... mainly represented by a dark grey, fine-grained meta-argillite with irregularly spaced magnetite rich laminae up to 3 mm thick" (Coombe, 1978, p.94).

The **quartzite-phyllite** unit consists of intercalations of coarse-grained grey feldspathic quartzite and fine-grained dark grey mica schists.

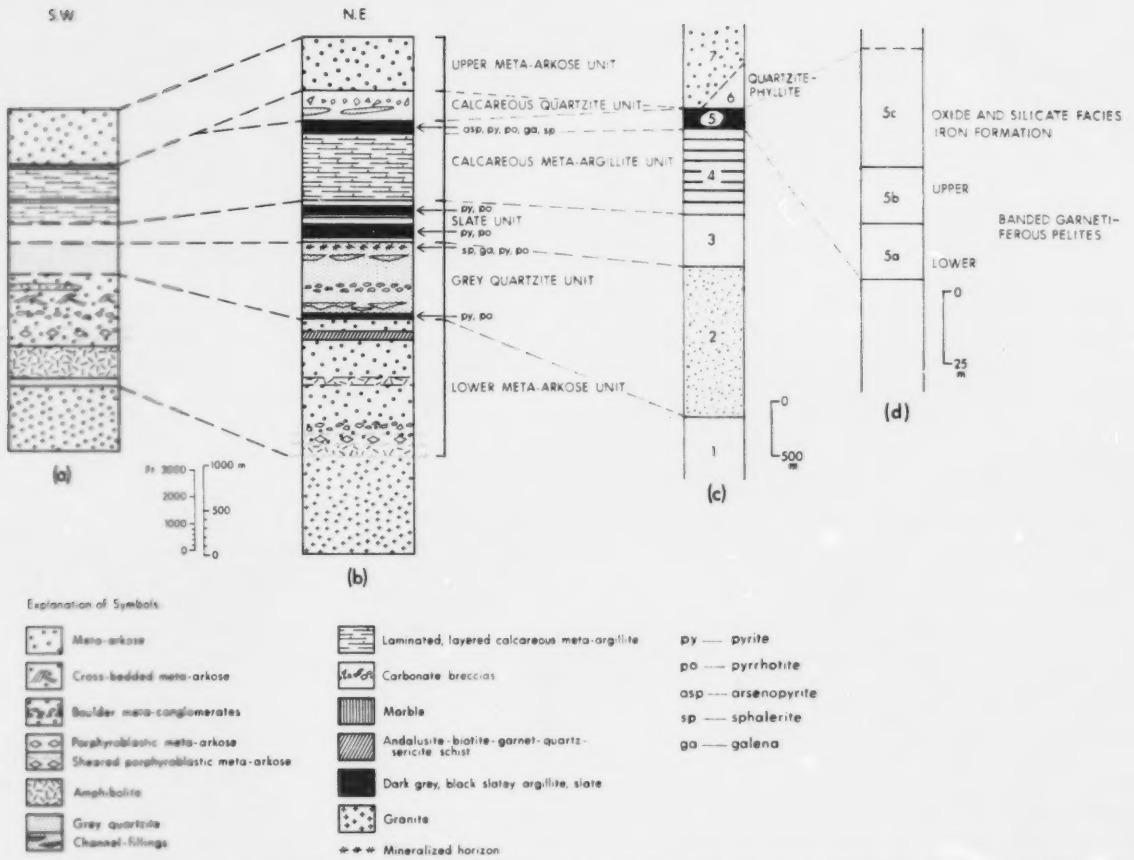


Figure 16. *Stratigraphic sections on the southeastern limb of the Courtenay-Cairns Lake belt: (a) northeast of Courtenay Lake, (b) at George Lake, and (c) at Spence Lake. Details of the sequence in the banded iron formation (Unit 5) are shown in (d). Modified from Coombe (1977, Figure 3 and 1978, Figure 2).*

The **upper meta-arkose** unit consists of fine- to medium-grained, massive to well-bedded meta-arkoses which show strong light grey and pink colour banding. Parts of the unit are calcareous, containing actinolite- and epidote-rich layers.

In both the George Lake and Spence Lake areas, the northwestern or marginal pelites adjacent to the Johnson River granite are thought by Coombe (personal communication, 1980) to be facies equivalents of all or parts of the lower three or four metasedimentary units (Coombe, 1977, 1978). In the George Lake area, it is possible to divide the pelitic sediments into northwestern and southeastern groups. The 'northwestern pelites' are generally massive, mottled red-brown and dark grey schists containing variable amounts of biotite, muscovite, garnet and sillimanite. Thin psammitic bands ($\leq$15 cm thick) and massive tremolitic quartzites (30 to 50 m thick) are also present. Muscovite-rich pegmatites, 10 to 15 m thick, cut the pelites subparallel to both the layering and the foliation. The 'southeastern pelites' are more heterogeneous, contain little garnet and sillimanite, are grittier in texture, and are intercalated with cherts, cherty quartzite and calc-silicates. Further to the southeast, the rocks become more pelitic, contain thin psammitic layers and consist of up to 70 percent dark green-black hornblende. Pyrite and pyrrhotite are common in trace amounts throughout the rocks but are more abundant in the more siliceous layers.

Sedimentation and Origin of the Iron Formation

The fine-grained and chemical sediments of the Courtenay-Cairns Lake belt indicate rather stable conditions. However, initial sedimentation in the Courtenay-Cairns Lake basin occurred under a more agitated and variable flow regime, as indicated by granular, conglomeratic, cross-bedded and scour-and-fill arkoses and quartzites. Instability is possibly also indicated by the presence of mafic volcanics in the lower arkose unit. The initial period of sedimentation and volcanism has been compared to the initial stages of rifting or aulocogen development (Coombe, personal communication, 1977), similar to the model described by Martin and Porada (1977) for the evolution of the Damara Orogen in southern Africa. Using this model, it appears that, following initial rifting, the structure stabilized but continued to subside under the weight of the sediments. The grey quartzite unit was succeeded by more stable restricted conditions which led to the deposition of shales, silts, clastic and chemical calcareous (and evaporitic) sediments, and iron formation, in addition to periodic influxes of coarser clastic detritus. A return to coarse clastic sedimentation is indicated by the upper arkoses. Equivalents of this arkose are extremely widespread throughout most of the Wollaston Domain and are considered by some (Weber et al., 1975) to be continental blanket sandstones.

The lateral persistence of the iron formation and the general stratigraphy of the Courtenay-Cairns Lake belt are features similar to those typical of Superior-type iron formations. A volcanic association is present in the lower part of the succession but cannot be demonstrated in the upper part. Whether the source of iron is continental or distant volcanic cannot be determined from the available information.

Structure and Metamorphism

The Courtenay-Cairns Lake belt occupies a northeast-trending synform with steeply dipping limbs. In addition to the primary sedimentary structures, two ages of foliation (S_1 and S_2) are commonly developed (Coombe, 1977, 1978). The S_1 foliation is parallel to bedding (S_0) except where the rocks are tightly folded by F_1. The F_1 folds are shallow and southwesterly plunging on subvertical axial planes, and a rodding lineation (L_1) is developed parallel to the fold axes. A strain-slip cleavage (S_2), with strikes of 035 to 040°, is locally developed in the cores of Z-shaped F_2 folds which plunge steeply northeast and have subvertical axial planes trending 035 to 040°.

A number of north-trending faults cross the Spence Lake area. The left-lateral offset of geological features and magnetic trends indicates up to 600 m of movement along these faults.

Peak metamorphic conditions (upper greenschist to lower amphibolite facies) appear to have accompanied the F_1 folding (Scott, 1970; Coombe, 1977, 1978). The grade appears to increase towards the northwest and southeast margins of the fold belt.

Geochemistry

Whole rock analyses of grab samples collected by Coombe in 1977 and 1978 from outcrop west of and at the northeast end of Spence Lake are shown in Table 12. The total iron values, which include iron in both oxide and silicate minerals, are not truly indicative of the amount of extractable iron in the rocks. Samples 77-500, 78-03, 78-05, 78-E and 78-F, which are dominantly oxide facies iron formation, have an average total Fe content of 22.0 percent, a figure which is probably close to the amount of extractable iron present. Samples 78-01 to 78-06 and 78-D to 78-G have weighted average Fe contents of 22 percent over a width of 9 to 10 m and 21.37 percent over 80 m respectively. Both are well below the desired grade of 30 percent.

Table 12. Whole Rock Analyses of Samples from the Iron Formation Unit, Spence Lake (modified from Coombe, 1978). All values in Weight Percent

	78-01[1]	78-02[1]	78-03[1]	78-04[1]	78-05[1]	78-06[1]	77-500[2]	77-106[2]	77-210[2]	78-C[1]	78-D[1]	78-E[1]	78-F[1]	78-G[1]
Fe^3	25.9	21.2	21.9	16.8	26.0	19.8	19.1	14.8	17.1	7.5	21.6	19.9	23.1	20.9
FeO	26.7	20.3	16.8	17.0	14.5	14.4	14.9	16.3	21.0	4.0	10.5	17.2	19.9	24.6
Fe_2O_3	7.4	7.7	12.7	8.0	21.1	12.3	10.7	3.0	1.1	6.4	19.3	9.4	10.9	2.6
SiO_2	46.3	54.7	52.7	60.1	51.5	57.6	53.8	63.4	47.3	61.6	57.3	56.7	53.1	53.1
Al_2O_3	7.4	8.9	5.6	7.1	4.0	6.3	5.9	8.5	16.3	13.5	7.0	7.1	6.2	7.2
MnO	3.8	0.6	3.8	1.0	1.0	1.7	3.3	0.3	0.3	0.5	2.8	2.4	2.8	3.0
P_2O_5	nd	nd	nd	nd	nd	nd	0.3	0.2	0.2	0.2	0.3	0.25	0.3	0.3
CaO	2.0	0.9	3.0	1.2	3.2	3.3	6.1	2.2	2.2	1.45	3.4	1.85	1.85	4.8
MgO	5.5	5.7	4.6	4.7	3.9	3.9	3.6	3.4	6.2	2.7	3.4	4.4	4.2	4.3
K_2O	0.2	0.2	0.05	0.2	0.05	0.2	0.5	1.6	2.8	5.8	1.5	0.6	0.4	0.1
Na_2O	0.1	0.2	0.1	0.1	0.1	0.2	0.2	0.2	0.4	3.0	0.65	0.2	0.1	0.2
TiO_2	nd	nd	nd	nd	nd	nd	0.4	0.5	0.6	0.85	0.4	0.45	0.35	0.4
S	0.05	0.02	0.04	0.04	0.03	0.01	0.01	0.01	0.01	0.02	0.01	0.01	0.01	0.01
H_2O	nd	nd	nd	nd	nd	nd	0.04	0.1	0.19	nd	nd	nd	nd	nd
LOI	nd	nd	nd	nd	nd	nd	0.00	0.00	0.00	nd	nd	nd	nd	nd
C	0.01	0.03	0.05	0.05	0.03	0.05	nd	nd	nd	nd	nd	nd	nd	nd
Totals	99.45	99.25	96.39	99.49	99.36	100.01	99.75	99.81	99.60	100.02	100.56	108.56	100.1	100.61

Samples 78-01 to 78-06 collected at 1.5 m intervals across width of exposed iron formation northwest of Spence Lake.
78-01 Laminated mixed silicate-oxide facies; less than 5 percent magnetite
78-02 Richly garnetiferous transition silicate-oxide facies
78-03 Mesobanded oxide (minor silicate) facies
78-04 Silicate facies interlayer
78-05 Typical mesobanded oxide facies
78-06 Silicate facies interlayer

77-500 Mesobanded oxide-silicate iron formation, northwest of Spence Lake
77-106 Banded garnetiferous pelite, upper subunit (5b), southwest end of Spence Lake
77-210 Banded garnetiferous amphibole-bearing pelite, lower subunit (5a), same location as 77-106

Samples 78-C to 78-G collected by Coombe at 6 m intervals across exposed iron formation at northeast end of Spence Lake
78-C Magnetite argillite
78-D Silicate-oxide facies
78-E Oxide facies
78-F Oxide facies
78-G Silicate-oxide facies

[1]Analyzed by Bondar-Clegg and Company Limited, Vancouver

[2]Analyzed by University of Regina

[3]$Fe = 0.7773FeO + 0.6994Fe_2O_3$
nd = not determined

Most of the impurities are within acceptable limits and could be lowered still further during concentration. The fine grain size of the rocks would necessitate very fine grinding for proper liberation of the iron by magnetic separation.

Geophysics

On aeromagnetic maps 2744G and 2745G (Geological Survey of Canada, 1963a, b) the areas of iron formation shown in Figure 15 are indicated by small linear anomalies, 300 to 400 gammas above background, which appear to be insignificant when compared to the higher regional magnetic expression of the lower meta-arkose unit and the Johnson River granite. Only a single band is discernible from the aerial survey, but detailed ground surveys indicate the presence of two bands (Figure 15) folded about the synclinal axis. Convergence of the ground magnetic anomalies near the southwest end of Cairns Lake, 8 km northeast of Spence Lake, suggests a closure of the syncline.

Economic Evaluation

The Spence Lake iron formation has some of the desired qualities of a good iron ore and is in close proximity to existing roads. Although the nature, extent and grade has not been thoroughly investigated along its entire length, the occurrence is considered uneconomic at present. Much of the iron is probably tied up in silicate minerals, thereby reducing the tonnage, grade (less than 22 percent) and mineable width of the deposit. The few sampled sections suggest a thickness of less than 20 m for the oxide facies rocks. Repetition of the formation by folding is of little help in increasing the tonnage because the two bands are separated by as much as 0.5 to 1 km. Finally, the very fine grained nature of the rocks would increase the cost of concentration.

Iron Sulphide Type

Nistoassini Lakes

Large sulphide-bearing zones were discovered as early as 1928 in the Nistoassini-Waddy Lakes area. Since then the area has been re-examined many times for its gold and base metal potential. Reports of exposures of barren massive sulphide deposits 21 to 24 m thick (Alcock, 1938; Byers, 1948) prompted a re-evaluation of the area for iron. Preliminary investigations (Harper, 1974) indicated that further work was warranted. Studies carried out in 1976 (Harper, 1976) indicated that the area has excellent potential as a source for iron. Although it has been extensively explored for base metals and gold, there is also still considerable potential for these commodities.

Geology

The Lower Nistoassini Lake area lies in the La Ronge Domain and is underlain by upper greenschist facies grade mafic to felsic volcanics and associated volcaniclastics and sediments, which together form a belt with a maximum width of 20 km (Figures 1 and 17). Primary volcanic and sedimentary structures are common, so that a reasonably coherent stratigraphy can be worked out (Table 13).

Table 13. Table of Formations[1], Nistoassini Lakes Area

Pleistocene to Recent		Silt, sand, gravel, till, iron-cemented tillite, bog iron ore, peat
		——— Unconformity ———
Aphebian	10	Granodiorite; Nistoassini-Nayelles Lake and Kenwood River bodies
	9	Diorite, quartz diorite
	8	Gabbro
	7	Pyroxenite
		——— Intrusive Contacts ———
	6	*Western Sediments*; arkose, arkosic and polymict conglomerates, greywacke and tuff (in part contemporaneous(?) with 1, 2 and 3)
		— Uncertain Stratigraphic Relation —
	5	*Upper Mafic Volcanics*; basaltic to andesitic flows, pillows, agglomerate, tuffs, minor felsic flows and pyroclastics
	4	*Felsic Volcanic Breccia*
	3	*Greywacke-Argillite*; also pyritic-carbonaceous shales, lithic tuffs, chert and minor felsic volcanics; in part staurolite-bearing
	2	*Felsic Volcanics*; dacitic to rhyolitic tuffs, flows and coarse pyroclastics, in places capped by Subunit 2a, sulphide-bearing breccia, rhyolite agglomerate and conglomerate
	1	*Lower Mafic Volcanics*; basaltic to andesitic flows, pillows and pyroclastics

[1]Numbers correspond to those in Figure 17.

Whole rock analyses (Table 14 and Figure 18) show that the volcanic rocks are transitional in composition between rocks of tholeiitic and calc-alkaline affinities. Irvine and Baragar (1971) indicate that compositions straddling the two fields are common and that a tholeiitic component is often characteristic of Archean and Proterozoic greenstone belts. In the alkalis versus SiO_2 plot (Figure 18b), the volcanics, particularly the felsic end members, may have undergone silicification with a concomittant loss of alkalis. The alkalis versus $Fe_2O_3 + Fe + \frac{1}{2}(MgO + CaO)$ plot (Figure 18c and Church, 1975) indicates a close similarity between the Nistoassini volcanics and the Cascade volcanics considered by some (Irvine and Baragar, 1971) to be calc-alkaline. The loss of alkalis is again suggested for the acid end members in Figure 18c. Similar results have been obtained by Watters (personal communication, 1978) for volcanics of the La Ronge Domain.

The volcanic complex is centred about a triangular domal structure which has a major northeast-trending axial plane. This structure is bounded by parallel synclines and anticlines which are cut off to the north by the Nistoassini-Nayelles Lakes granodiorite and to the west by the Kenwood River granodiorite (Byers, 1948). To the south the structures can be traced for nearly 15 km. On a local scale, structure is influenced by the numerous small gabbroic to granitic stocks and sills that intrude the complex.

Barren massive sulphides are found mainly at the top of the felsic volcanic sequence, within an overlying succession of greywackes and tuffaceous, carbonaceous and chemical sediments, and less commonly in other horizons above the sediments.

Rock Descriptions

The **lower mafic volcanics** unit, consisting of massive basaltic to andesitic flows, finely laminated tuffs, pillow lavas and other pyroclastics, occurs in the core of the major domal structure north of Lower Nistoassini Lake. The rocks are generally dark green, fine to medium grained and hornblende bearing. Ellipsoidal quartz variolites occur in some flows and pillows. Sills and/or flows of felsic volcanics are more numerous towards the top of the sequence. Felsic fragments are abundant in the agglomerates.

The **felsic volcanics** form a major part of the volcanic sequence in the area, attaining a maximum thickness of 600 to 700 m around the mouth of the Kenwood River and at Pillow Lake. A second section at the south end of Lower Nistoassini Lake is almost 450 m thick. The felsic volcanics consist of flows, tuffs and coarser pyroclastics that vary in composition from

dacite to rhyolite. The upper 100 to 200 m consists largely of felsic tuffs and rhyolite flows up to 5 m thick (Plate 7). The top of the felsic pile is capped in places by sulphide-bearing explosion breccias (Plate 8), rhyolite agglomerate and conglomerate (Plate 9). These rocks may also contain some interlayered fine-grained clastic and chemical sediments. In addition to rhyolite clasts, the conglomerate contains rounded clasts of sugary quartzite and arkose. In the few places where granitic and mafic volcanic clasts are found, they are closely associated with banded pyritic-carbonaceous sediments and massive sulphides. The breccia and conglomerates are similar to rocks found in hydrothermal explosion craters in Yellowstone National Park (Muffler et al., 1971).

The felsic volcanics are aphanitic, conchoidally fracturing and white, pink or grey to black. Except for the tuffaceous varieties, layering is nonexistent, and only a weak metamorphic foliation is present. Quartz and/or feldspar crystal tuffs and porphyritic flows or intrusions occur in places; the phenocrysts in these are normally less than 0.5 cm in diameter but range up to 2 cm.

The **greywacke-argillite** sequence, which overlies the felsic volcanics, reaches a maximum thickness of 300 m but pinches out to the east along both the northern and southern bands of felsic volcanics. This unit consists of finely laminated tuffaceous sediments, greywacke, argillite, banded pyritic carbonaceous shale, minor chert beds, and mafic

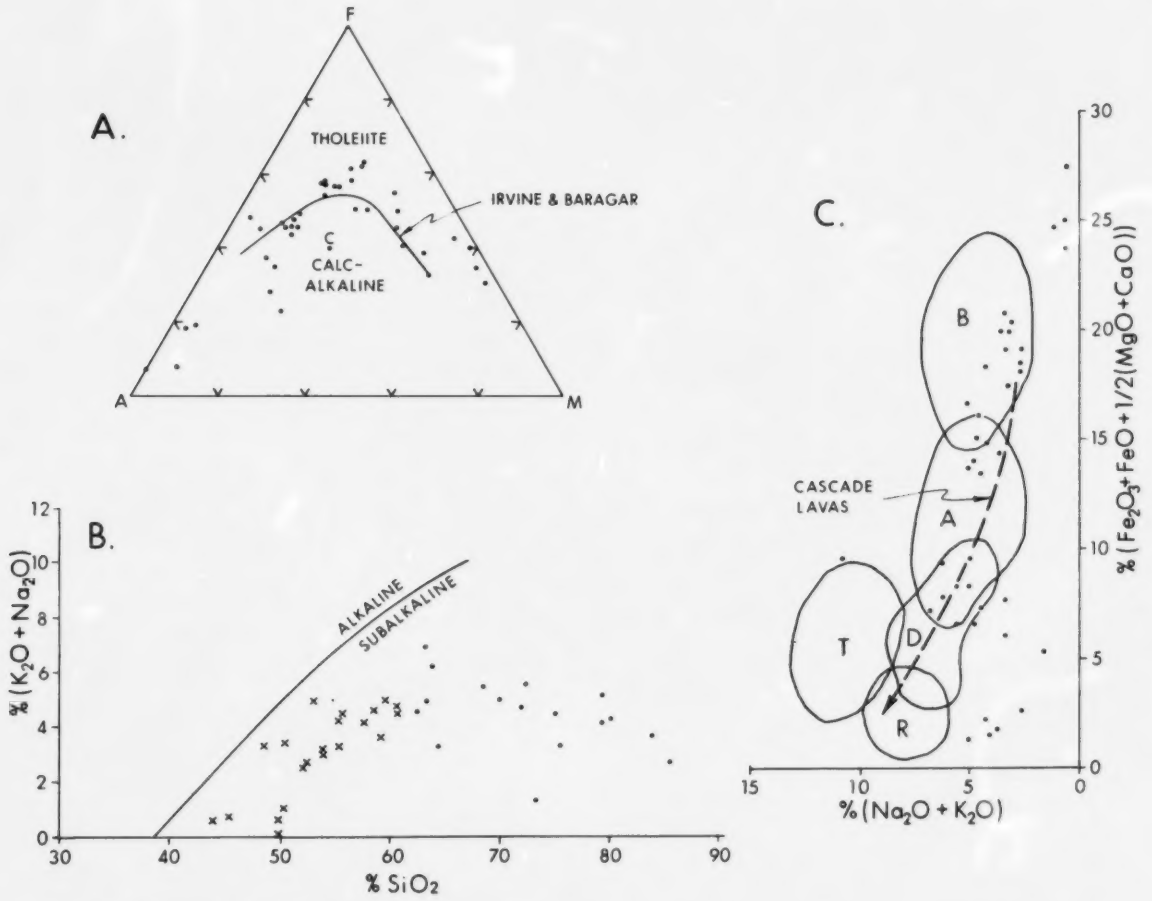
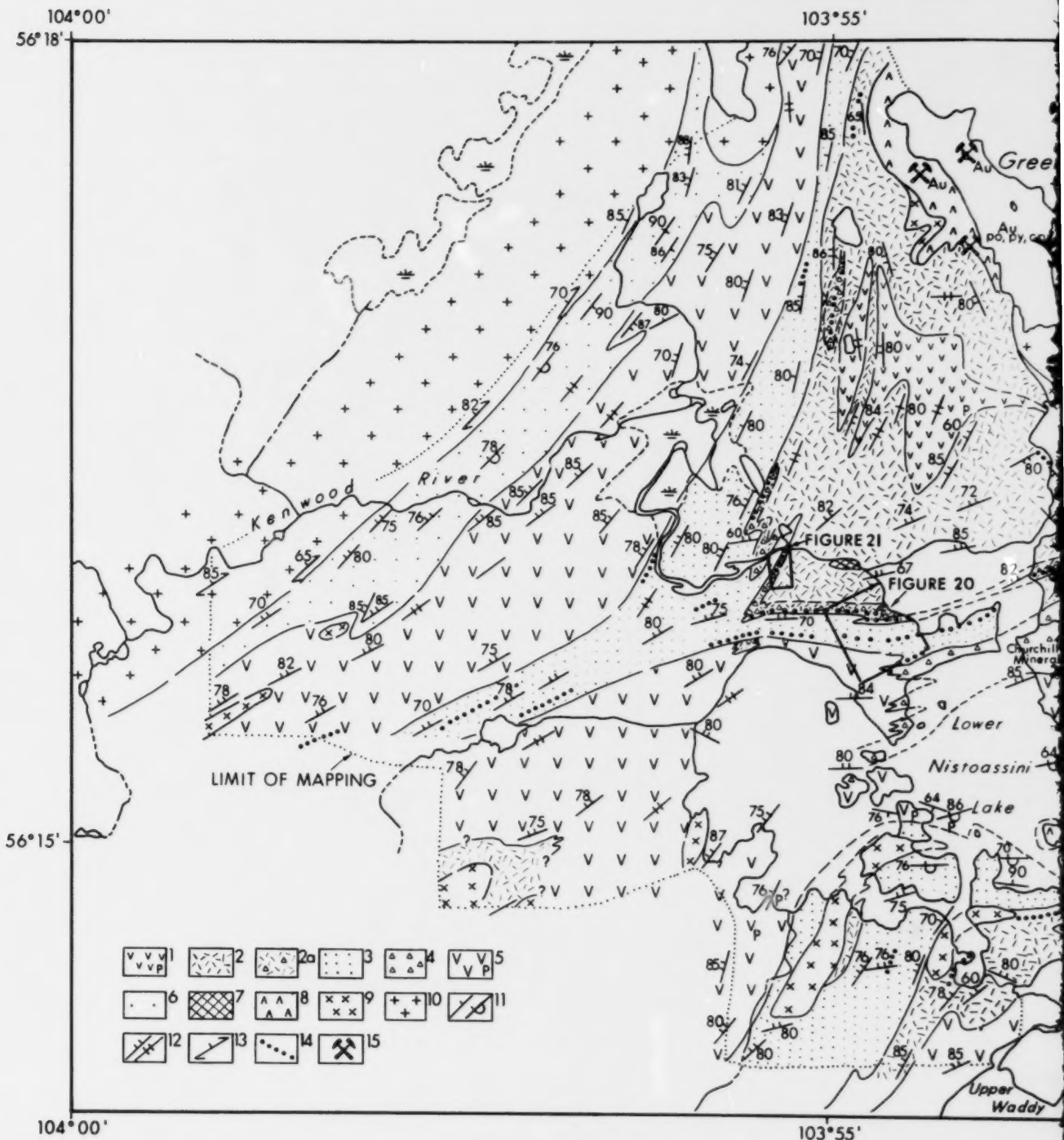
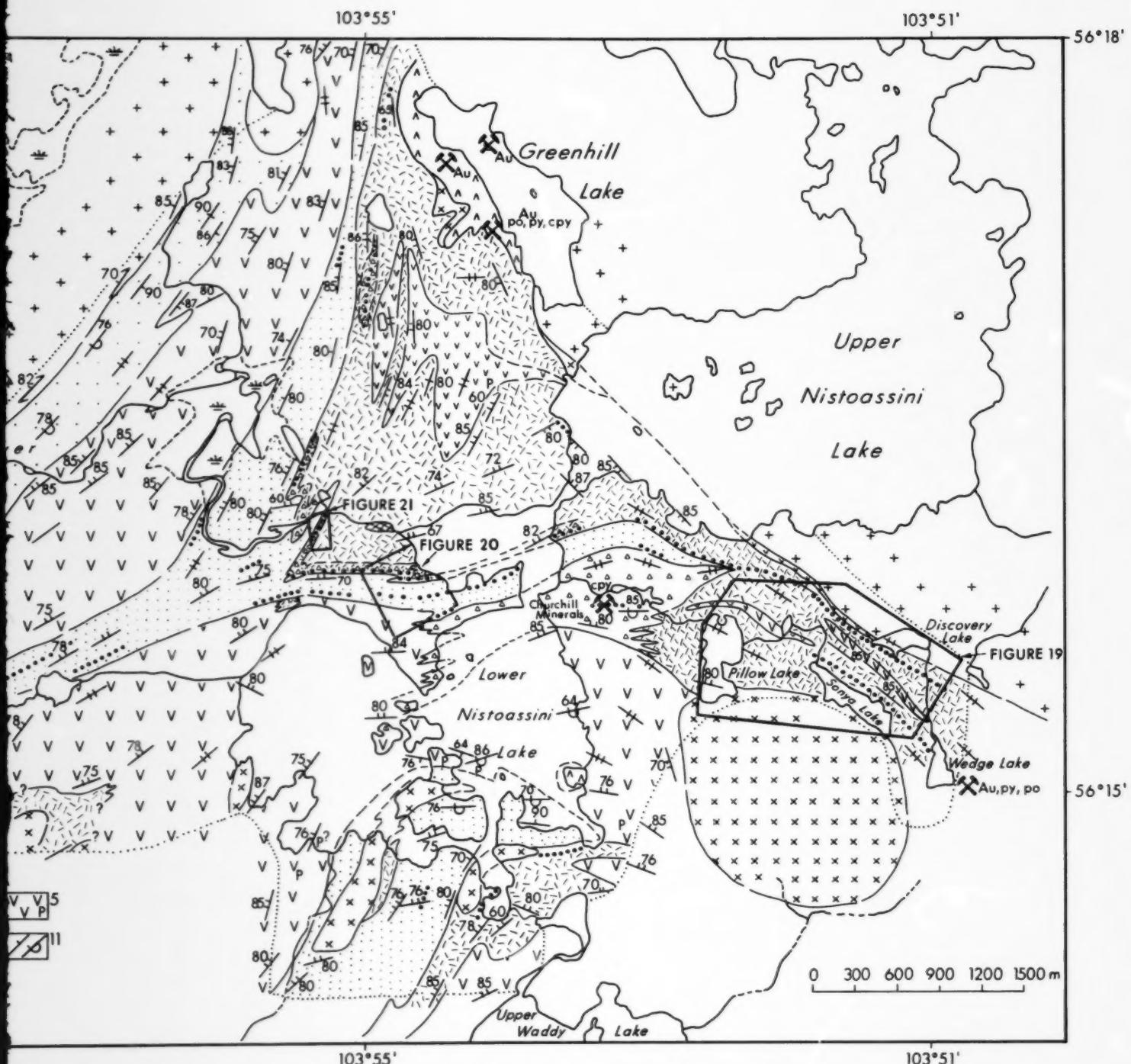


Figure 18. *Geochemical relations for Nistoassini volcanic rocks:*
A. AFM ternary diagram. Curve separating tholeiitic and calc-alkaline rocks as defined by Irvine and Baragar (1971); A = $K_2O + Na_2O$; F = $FeO + 0.8998\ Fe_2O_3$; M = MgO (all in weight percent).
B. Alkalis versus SiO_2, with alkaline and subalkaline fields as defined by Irvine and Baragar (1971); x = field designated basalt/andesite; • = field designated dacite to rhyolite.
C. Alkalis versus $Fe_2O_3 + FeO + ½(MgO+CaO)$. Trend line for Cascade Lavas after Church (1975). Identified fields are: B, basalt; A, andesite; D, dacite; R, rhyolite; T, trachyte.


104°00'
103°55'
56°18'
56°15'
Kenwood River
LIMIT OF MAPPING
FIGURE 21
FIGURE 20
Lower
Nistoassini
Lake
Upper
Waddy
Au
Au
Au



kes area. Compiled from field work by the author (Harper, 1974, 1976). 1, lower mafic volcanics (P, pillowed); 2, felsic volcanics; 2a, nd conglomerate; 3, greywacke-argillite; 4, felsic volcanic breccia; 5, upper mafic volcanics (P, pillowed); 6, western sediments: arkose, tuff (in part contemporaneous with 1, 2 and 3); 7, pyroxenite; 8, gabbro; 9, diorite, quartz diorite; 10, granodiorite to granite; 11, bedding, nknown (inclined, vertical); 13, foliation (inclined); 14, major sulphide zone; 15, mineral occurrence (Au, gold; py, pyrite; po, pyrrhotite;

Table 14. Whole Rock Analyses, Lower Nistoassini Lake Area. All Values in Weight Percent

	1 *H087*	*2* *B367*	*3* *H043*[1]	*4* *H103*	*5* *H167*[1]	*6* *H175*	*7* *H024*	*8* *H033*[1]	*9* *B164*	*10* *H050*[1]	*11* *H084*[1]	*12* *H084*	*13* *H047*	*14* *H083*[1]
SiO_2	44.1	45.6	48.7	50.0	50.3	50.5	52.2	52.4	53.1	53.9	53.9	54.0	55.5	55.6
Al_2O_3	3.8	9.7	12.9	6.9	9.7	14.2	16.0	15.7	16.2	16.9	14.1	14.0	8.7	14.4
FeO	11.0	6.79	-	6.95	-	8.30	10.5	-	8.75	-	-	10.9	6.05	-
Fe_2O_3	2.10	4.10	9.5	1.64	11.7	2.22	2.65	10.0	2.58	11.1	13.7	3.00	1.93	12.7
MgO	19.0	18.7	11.9	17.9	14.6	8.60	7.90	7.3	6.20	3.6	4.8	4.80	12.0	5.0
CaO	9.70	9.5	10.5	12.2	11.4	10.1	2.70	8.8	6.30	9.0	7.5	8.10	10.1	6.1
K_2O	0.18	0.05	1.7	0.05	0.20	1.15	0.75	0.37	0.28	0.02	0.62	0.67	0.31	0.7
Na_2O	0.35	0.61	1.7	0.60	0.93	2.40	1.93	2.4	4.80	3.2	2.6	2.35	3.00	3.5
P_2O_5	0.08	0.13	0.75	0.01	0.69	0.26	0.09	0.52	0.11	0.50	0.51	0.29	0.22	0.3
MnO	0.20	0.17	0.17	0.17	0.21	0.18	0.12	0.17	0.17	0.14	0.18	0.21	0.15	0.19
TiO_2	0.27	0.29	0.86	0.03	0.57	0.83	0.98	0.40	0.62	0.90	1.4	1.25	0.50	1.3
H_2O^+	-	-	1.07	-	-	-	-	1.47	-	0.46	0.90	-	-	0.94
H_2O^-	-	-	0.53	-	-	-	-	0.74	-	0.53	0.13	-	-	0.12
H_2O	1.72	3.70	-	2.00	-	0.42	3.53	-	0.38	-	-	0.29	0.71	-
CO_2	6.88	0.21	-	0.64	-	0.42	0.35	-	0.14	-	-	0.25	0.42	-
Total	99.38	99.55	100.28	99.09	100.30	99.58	99.70	100.25	99.63	100.25	100.34	100.11	99.59	101.0

1 and 3 - Gabbro
2, 4 to 6 - Basalt flows
7 to 20 - Andesitic volcanics (flows and tuffs)
21 to 29 - Dacite-rhyodacite
30 to 39 - Rhyolite

[1]analyzed by University of Regina, with total Fe being given as Fe_2O_3; remainder of analyses by Bondar-Clegg and Company Limited, Vancouver
ND = not detected
- = not analyzed
all sample numbers have the prefix 7615

sini Lake Area. All Values in Weight Percent

3	5 H167[1]	6 H175	7 H024	8 H033[1]	9 B164	10 H050[1]	11 H084[1]	12 H084	13 H047	14 H083[1]	15 B136[1]	16 B360	17 H064[1]	18 H027	19 H153	20 H046[1]	21 H051[1]	22 H136A
)	50.3	50.5	52.2	52.4	53.1	53.9	53.9	54.0	55.5	55.6	55.8	57.9	58.8	59.2	59.5	60.9	61.8	62.6
)	9.7	14.2	16.0	15.7	16.2	16.9	14.1	14.0	8.7	14.4	17.1	16.2	14.8	15.2	15.6	14.3	14.3	14.5
5	-	8.30	10.5	-	8.75	-	-	10.9	6.05	-	-	7.01	-	7.33	7.65	-	-	8.36
4	11.7	2.22	2.65	10.0	2.58	11.1	13.7	3.00	1.93	12.7	10.8	2.64	10.4	2.00	2.36	10.7	7.6	2.50
)	14.6	8.60	7.90	7.3	6.20	3.6	4.8	4.80	12.0	5.0	3.8	2.75	3.0	5.50	3.20	3.0	3.6	3.60
)	11.4	10.1	2.70	8.8	6.30	9.0	7.5	8.10	10.1	6.1	6.8	7.40	6.2	4.50	4.00	3.5	0.40	1.50
5	0.20	1.15	0.75	0.37	0.28	0.02	0.62	0.67	0.31	0.78	1.6	1.00	1.2	0.40	2.92	0.30	6.6	2.98
0	0.93	2.40	1.93	2.4	4.80	3.2	2.6	2.35	3.00	3.5	2.93	3.20	3.5	3.30	2.15	4.5	4.2	1.53
1	0.69	0.26	0.09	0.52	0.11	0.50	0.51	0.29	0.22	0.39	0.39	0.20	0.37	0.18	0.23	0.32	ND	0.13
7	0.21	0.18	0.12	0.17	0.17	0.14	0.18	0.21	0.15	0.19	0.14	0.17	0.14	0.14	0.11	0.16	0.03	0.03
3	0.57	0.83	0.98	0.40	0.62	0.90	1.4	1.25	0.50	1.3	0.70	0.53	0.98	0.87	0.67	0.87	0.74	0.67
	-	-	-	1.47	-	0.46	0.90	-	-	0.94	-	-	0.93	-	-	0.93	0.81	-
	-	-	-	0.74	-	0.53	0.13	-	-	0.12	-	-	0.33	-	-	0.74	0.37	-
0	-	0.42	3.53	-	0.38	-	-	0.29	0.71	-	-	0.18	-	0.87	0.87	-	-	0.96
4	-	0.42	0.35	-	0.14	-	-	0.25	0.42	-	-	0.35	-	0.31	0.42	-	-	0.14
9	100.30	99.58	99.70	100.25	99.63	100.25	100.34	100.11	99.59	101.02	100.30	99.53	100.66	99.80	99.68	100.22	100.45	99.50

being given as Fe_2O_3; remainder of analyses by Bondar-Clegg and Company Limited.

23 *H080*[1]	*24* *B188*	*25* *H044*[1]	*26* *H125*	*27* *H079*[1]	*28* *H041A*	*29* *H041*[1]	*30* *H124*	*31* *H032*[1]	*32* *H038*[1]	*33* *H040*[1]	*34* *H074*	*35* *H077*[1]	*36* *H056*[1]	*37* *H022*	*38* *H509*	*39* *H505*
63.3	63.4	63.6	63.9	64.5	68.5	70.0	72.0	72.4	73.2	75.1	75.5	79.2	79.2	80.0	83.8	85.2
17.0	16.5	15.1	18.0	10.3	13.6	12.5	13.0	13.2	13.9	9.3	11.6	12.4	11.6	11.6	9.0	7.2
-	2.44	-	3.60	-	4.12	-	3.47	-	-	-	3.47	-	-	0.58	0.58	0.77
6.3	1.29	7.4	1.29	3.7	2.29	6.8	1.22	5.4	3.5	5.5	0.86	0.50	0.38	0.50	0.43	0.43
4.0	2.36	2.3	1.57	1.0	2.37	2.0	0.73	0.4	3.7	1.8	1.30	ND	0.44	0.22	0.29	1.20
2.4	4.40	1.6	4.15	6.9	1.35	1.1	3.00	2.0	0.10	2.0	2.05	1.9	2.0	2.15	1.25	1.45
1.1	1.80	1.8	1.40	0.80	1.45	1.1	1.98	2.0	0.91	1.5	0.60	0.88	0.62	0.60	0.40	0.50
3.9	5.10	4.5	4.85	2.6	4.20	4.0	2.83	3.6	0.54	2.9	2.10	4.3	3.5	3.75	3.35	2.20
0.37	0.26	0.08	0.22	0.12	0.11	0.06	0.09	0.11	ND	0.12	0.12	0.10	0.09	0.16	0.12	0.05
0.09	0.06	0.08	0.08	0.10	0.10	0.09	0.07	0.11	0.07	0.08	0.08	ND	0.01	0.01	0.01	0.01
0.68	0.25	0.67	0.38	0.20	0.37	0.46	0.21	0.35	0.20	0.33	0.30	0.38	0.27	0.32	0.22	0.15
0.53	-	2.25	-	0.79	-	1.67	-	0.60	3.23	0.88	-	0.38	1.43	-	-	-
0.17	-	0.92	-	0.27	-	0.44	-	0.57	0.76	0.73	-	0.19	0.34	-	-	-
-	0.40	-	0.52	-	0.72	-	0.57	-	-	-	0.50	-	-	0.01	0.01	0.21
-	1.13	-	0.35	-	0.35	-	0.18	-	-	-	0.38	-	-	0.59	0.35	0.17
99.84	99.39	100.30	100.31	91.28	99.53	100.22	99.35	100.66	100.11	100.27	99.56	100.23	99.88	100.49	99.81	99.54

and felsic dykes, sills and/or flows. Lenses of barren massive sulphides, many with sedimentary structures, occur near or at the base and top of the unit. Closely associated with and perhaps related to the sulphide zones are greenish siliceous rocks (chert or rhyolite) that contain disseminated pyrite and pyrrhotite.

The sediments are aphanitic, fine grained and light to dark grey on fresh and weathered surfaces. Splotchy iron stain is common where disseminated iron sulphides are present. Sedimentary structures include graded and cross-bedding, truncated beds, slump features and laminations typically less than 1.0 mm thick (Plate 10).

The rocks consist mainly of quartz, feldspar and biotite, but also contain porphyroblasts of blue-green hornblende, garnet and staurolite. Garnet is generally more abundant than staurolite, but both show a marked increase in size and abundance towards the hinge zone of the major southwesterly trending triangular anticline.

A thick succession of up to 400 m of **felsic volcanic breccia** (Figure 17) is associated with and extends westward from the Pillow Lake felsic dome (Smith et al., 1973). Pyroclastic breccias occur to the east of Pillow Lake but are much less significant. The base of the unit consists of large felsic volcanic fragments, up to 0.3 by 1 m in size, in an intermediate to mafic matrix consisting largely of biotite and chlorite. Fragments decrease in size upwards and westwards, with a corresponding increase in the proportion of matrix (Plate 11). The rock varies in colour from green to dark green-black, and white stripes or spots are common. The fragments are mainly felsic volcanics, but mafic fragments become more abundant higher in the succession. A few granitic clasts are also present. The pyroclastic unit grades into the overlying upper mafic volcanics. The only copper occurrence of note, the Churchill Minerals showing, is located within this pyroclastic wedge.

The **upper mafic volcanic** unit in the Lower Nistoassini-Pillow Lakes area consists largely of interlayered mafic tuffs, massive flows, volcaniclastic sediments, pillow lavas and sills of diorite and gabbro. Localized felsic volcanism is indicated by small dacitic to rhyolitic domes and quartz and/or feldspar porphyry sills.

The tuffs and flows, typically dark green to green-grey, are aphanitic to fine grained and well laminated or massive. Pillow lavas (Plate 12) are exposed at several localities in the southern part of the area, but are best exposed on Pillow Island[1], a small island in Lower Nistoassini Lake. The pillowed zone, about 30 m thick, is intensely folded in the form of S-shaped kink folds. The pillow lavas, which are dark green on fresh surfaces, pale green on weathered surfaces and fine grained, contain considerable chlorite. The pillows are stretched and their average size is about 30 by 20 cm and 10 cm in thickness.

The **western sediments** consist of arkose, arkosic and polymict conglomerate, greywacke and tuffaceous sediments. They form an area up to 450 m wide separating the upper mafic volcanics from the Kenwood River granodiorite. The following three units were mapped: (a) pink fine-grained arkose and granular arkose; (b) light to dark grey, aphanitic to fine-grained, finely laminated to thick-bedded greywacke turbidite, tuffaceous sediments and sandstones; and (c) a dominantly conglomeratic zone with arkosic and tuff-like interlayers. Round to elongate pebbles and cobbles (0.5 to 30 cm long) of arkose, dacitic-like volcanics, greywacke and granite are present (Plate 13). The conglomerates are pink to grey with a generally fine-grained matrix. 'Way-up' structures (Plate 14) are common in the greywacke zone and indicate an eastward younging succession. The stratigraphic relationship to the rest of the volcanic complex is still speculative.

Intrusive rocks have a variety of compositions and were probably intruded over a considerable time span. Their positions as shown in Table 13 are not necessarily the order in which they were intruded. In addition to the major bodies shown in Figure 17, many smaller dykes and sills occur throughout the area.

Pyroxenite occurs at the mouth of the Kenwood River. The rocks are poorly exposed, strongly altered, soft, greenish brown and coarse grained. No original minerals are preserved, the rocks having been completely altered to talcose material, chlorite and carbonate.

Gabbroic rocks are typically dark green to black, coarse grained, massive and unaltered. A small circular boss on the southeast shore of Lower Nistoassini Lake shows a sheared silicified contact with the surrounding mafic volcanics. Intrusive breccias, occurring along part of the southern contact of the Greenhill Lake body, contain angular to rounded gabbro fragments, up to 20 cm in diameter, that have bleached rims (Plate 15). Disseminated chalcopyrite occurs in the Greenhill Lake gabbro.

[1]Unofficial name.

Diorite and quartz diorite sills, dykes and stocks are common and range in size from a few tens of metres to as much as 1.5 km. Much of the border phase of the Nistoassini-Nayelles Lakes granodiorite is dioritic. The diorites and quartz diorites are mottled light and dark grey, weather pinkish grey in places, are generally coarse grained and contain 30 to 40 percent mafic minerals, normally hornblende and biotite with some pyroxene. Some are porphyritic with feldspar phenocrysts up to 1 cm long; although generally massive, some are weakly foliated. Disseminated pyrite and pyrrhotite, present in accessory amounts, cause local rusty iron stain.

Granodiorites form two large masses, the Nistoassini-Nayelles Lakes granodiorite (NN) and the Kenwood River granodiorite (KR), as well as several smaller bodies. The NN granodiorite is pink to grey on both fresh and weathered surfaces, has a grain size of 3 to 4 mm, is generally massive and shows a weak foliation near its contact with the volcanic and sedimentary rocks. Mafic minerals, generally hornblende and biotite, comprise up to 10 or 15 percent of the rocks but increase markedly toward the marginal, more dioritic rocks. The KR granodiorite is similar but slightly more gneissic. A small boss of notably less mafic granodiorite intrudes the greywacke-argillite unit south of the mouth of Kenwood River. A narrow metamorphic aureole up to 70 m wide is associated with the NN granodiorite; the volcanic and sedimentary rocks affected show upper amphibolite facies metamorphic effects. Coarser grain size and the beginnings of metamorphic segregation are obvious features of the aureole.

Surficial deposits of **iron-cemented till and bog iron ore** overlie many of the sulphide zones and occur in low swampy areas adjacent to these zones. The till consists of poorly sorted, angular to rounded pebbles and cobbles of many rock types contained in a granular to fine clayey groundmass that is mainly replaced by limonite-goethite. Many pebbles are highly weathered. The bog iron ores form poorly consolidated crusty deposits of limonite-goethite, commonly replacing organic matter in low swampy ground adjacent to or overlying sulphide zones. Pools associated with these zones are usually shallow, sulphurous-smelling and poorly vegetated.

Structure and Metamorphism

Primary sedimentary and volcanic features suitable for 'way-up' determinations include parallel, laminated, cross- and graded bedding, as well as scour-and-fill structures, flow contacts and pillow lavas. A weak northeasterly trending foliation occurs chiefly in major fold hinge zones. Primary layering and bedding dips steeply and follows major fold directions. Folding is mainly isoclinal, and the area is dominated by a triangular domal structure, flanked by isoclinal synclines parallel to the sides of the triangle. According to Gorman et al. (1978), structures of this nature in Archean greenstone belts are found where sheet-like shield volcanoes develop on subsiding sialic crust. Elsewhere in the area, structures are controlled by the various intrusive stocks and sills.

Metamorphism accompanying deformation reached upper greenschist to lowest amphibolite grade. Diagnostic minerals include chlorite, actinolite, biotite, blue-green hornblende, garnet and staurolite, typical of Barrovian-type metamorphism (Winkler, 1967). A narrow thermal aureole occurs along the contact of the NN granodiorite.

Metamorphic recrystallization of primary sulphide mineralization has occurred locally, resulting in a coarsening of grain size and the loss of primary textures. Pyrite is commonly euhedral and was apparently the last mineral to recrystallize.

Geochemistry

The analytical results from 141 channel and grab samples of sulphide mineralization, 39 whole rock volcanic samples and 508 soil samples from the Sonya-Discovery Lakes zone are summarized in Table 15.

Samples from a 24 m section of trench H1 (see Figure 20) averaged 23.25 percent soluble Fe and 3.54 percent C. An old trench at he northeast end of Sonya Lake (Figure 19; trench SD-3, Table 15), reopened by the author (Harper, 1974), yielded two 4.5 m sections averaging 29.13 and 34.13 percent Fe. Iron values of up to 42 percent were obtained in some trenches across shorter widths and in some high-grade grab samples.

The composition of soil samples in the Sonya-Discovery Lakes area shows an excellent correlation with the sulphide zones, particularly in the case of Fe, Cu, Zn and Pb.

Sulphide Mineralization

Iron sulphides can take the form of disseminated, veined, remobilized, nodular, bedded and massive occurrences. Bedded and massive types are the most important. Disseminated pyrite and less commonly pyrrhotite are present in most of the rock types other than the western sediments. Disseminated iron sulphides often form haloes around massive sulphide lenses.

Noneconomic concentrations of pyrite and pyrrhotite occur as stockwork veins, particularly in the

Table 15. Summary of Analytical Results, Lower Nistoassini Lake. All values in Weight Percent

Trench Number	Sample Interval	Length (m)	Fe	C
KR-1	Grab	-	39.95	
	Grab	-	15.45	
H-1	0-3	3	5.70	0.15
	3-27	24	23.25	3.54
	27-34.5	7.5	8.89	0.59
H-2	0-10.5	10.5	14.19	0.61
H-3	0-10.5	10.5	18.92	3.85
H-4	0-4.5	4.5	18.88	
	4.5-7.5	3	5.77	
H-5	0-1.5	1.5	25.21	
H-6	0-4.3	4.3	11.55	
H-7	0-7.5	7.5	6.07	
LN-1	0-3.0	3.0	12.70	
LN-2	0-3.0	3.0	23.93	
LN-3	0-3.0	3.0	19.53	
	10.5-16.5	6.0	13.15	
LN-4	Grab	-	26.40	
LN-5	Grab	-	42.00	
SD-1	Grab	-	24.70	
SD-2	0-3.0	3.0	25.90	
SD-3	0-7.5	7.5	15.91	
	12-13.5	1.5	18.00	
	13.5-18.0	4.5	34.43	
	18.0-19.5	1.5	10.30	28.64 (weighted average Fe content)
	19.5-24.0	4.5	29.13	
SD-4	0-6.0	6.0	13.65	
SD-5	0-18.0	18.0	9.65	
SD-6	0-3.0	3.0	39.40	
	3.0-6.0	3.0	9.25	
SD-7	Grab	-	29.20	
SD-8	0-3.0	3.0	12.85	
	3.0-9.0	6.0	33.88	
SD-9	Grab	-	35.95	
	Grab	-	33.60	
SD-10	Grab	-	17.45	

KR - Kenwood River trenches
H1 to H7 - excavated by author in 1974
LN - Lower Nistoassini trenches
SD1 to SD10 - Sonya - Discovery Lakes zone trenches

brecciated rhyolites. Many vein-like features associated with bedded and massive sulphides reflect remobilization of the host sulphides. Boudin necks, open fold closures and fractures are common sites for remobilized sulphides. Sphalerite occurs commonly in these coarser grained sulphides.

Pyrite-pyrrhotite nodules (Plate 16) up to 4 cm in diameter display rounded to flattened forms as well as radial and concentric growth patterns. The nodules, which occur in a 1 to 2 m thick zone in a pyritic-carbonaceous and massive sulphide host near the south end of Lower Nistoassini Lake, consist of an interlocking network of pyrite, pyrrhotite and carbonaceous material, together with accessory quartz and hornblende. Sulphide nodules of a similar nature have been described as syngenetically precipitated pyrite (Kalliokoski, 1965; Wright, 1965; Antun, 1967), diagenetic concretionary growths (Woolverton, 1960) and recrystallized host rocks engulfed by a sulphide magma (Rose, 1965). The carbonaceous nature of the host and the concretionary appearance of the nodules supports a syngenetic-diagenetic origin.

The bedded sulphide-type mineralization includes the pyritic-carbonaceous shales which are often intimately associated with massive sulphide mineralization. The pyritic shales, normally 3 to 10 m thick, are exposed only in trenches. These fine-grained rocks range from black to yellowish black, depending on their sulphide content, and are characterized by 1 to 5 mm thick pyrite layers alternating with siliceous-carbonaceous layers (Plate 17). The pyrite layers are 1 to 5 mm thick and composed mainly of recrystallized euhedral pyrite. Sulphides normally comprise 20 to 30 percent of the rock or as much as 60 percent locally. The shaly layers are exceptionally fine grained and dense, containing as much as 5 percent carbon. Small-scale penecontemporaneous slump folds (Plate 17) are common in these rocks. Pyrrhotite is the dominant sulphide mineral locally. The pyritic shales represent sulphide facies iron formation (James, 1954; Gross, 1959; 1965).

Massive sulphide mineralization, which includes rocks containing greater than 30 percent iron sulphides, occurs in lenses up to 20 m thick. Pyrrhotite is normally the dominant mineral and pyrite is subordinate; accessories include chalcopyrite, sphalerite and carbonaceous material. Layered pyrrhotite mineralization has been observed showing well-defined sedimentary structures such as bedding and cross-bedding (Plate 18); anhedral pyrrhotite grains, commonly less than 0.1 mm in size, make up 50 percent of these bedding layers. Fine-grained quartz, mica, carbon and sphalerite account for the remainder. In a few places pyrrhotite and pyrite layers alternate. Pyrrhotite, pyrite and sphalerite also occur as fracture fillings.

Brecciation of the primary (layered) mineralization results in a second type, consisting of clasts of the layered sulphides, carbonaceous shales and pyrite in a matrix of coarsely crystalline pyrrhotite (Plate 19). Euhedral pyrite grains range up to 1 cm in size. The sections composed of coarse-grained pyrrhotite may represent either primary minerals, now recrystallized, or additional phases of sulphide mineralization. The iron content of the massive pyrrhotite ores varies from 10 to 42 percent, with an average value of 20 percent.

Mineralized Zones

Barren massive sulphide mineralization with minor disseminations of chalcopyrite and sphalerite occurs

at several specific horizons in the Lower Nistoassini Lake area (Figure 17). The stratigraphically lowest zone occurs at or near the contact between the felsic volcanics and the overlying greywacke-argillite sedimentary sequence. The hosts are primarily rhyolite breccias, agglomerates, conglomerates and sulphide-facies iron formation. The next horizon, lying near the top of the greywacke-argillite sequence, is dominated by sulphide facies iron formation shales (bedded and massive bedded deposits). The third mineralized zone, the Sonya Lake-Churchill Minerals zone, is related to a later period of felsic volcanism (Pillow Lake felsic dome). Other sulphide zones exist, but most are probably of the same age as one of the three periods of sulphide deposition. The more important zones of mineralization will now be described.

The **Sonya Lake zone** extends from the northeastern end of Sonya Lake several kilometres southeast through Wedge Lake and beyond (Figures 17 and 19). It has strong EM and magnetic responses and is reported to be at least 24 m wide at its northeast end. The zone was tested with numerous trenches, poorly exposed and badly overgrown at the time of investigation. Trenches sampled (Table 15) indicate a significant iron content, although lateral and vertical variability is a common problem. A single drill hole record (Assessment File 64D04-NW-0013) suggests that mineralization is variable at depth.

The **Discovery Lake zone**, which is only exposed intermittently, extends from the east shore of Lower Nistoassini Lake southeastwards past Discovery Lake (Figures 17 and 19). Although the zone has an excellent EM response, the magnetic response is variable, perhaps reflecting variations in the pyrrhotite content. At least a dozen trenches expose sulphide lenses ranging from 0.25 to 3 m in thickness. Drill intersections of up to 120 m of sulphide mineralization have been reported (Assessment Files 64D05-SW-0052 and 0060). A grab sample (LN-5, Table 15) from a trench on the shore of Lower Nistoassini Lake had an Fe content of 42 percent.

The **Churchill Minerals zone**, about 750 m in length, lies between Pillow Lake and Lower Nistoassini Lake (Figure 17). It appears to be stratigraphically equivalent to the Sonya Lake zone. Extensive exploration work has been carried out on this zone since 1930 (Byers, 1948), principally by the Hudson Bay Mining and Smelting Company (Assessment Files 64D05-SW-0003, 0052, 0060 and 74A01-NE-0002 and 0003). They outlined a small copper deposit, 25 m long, 7.5 m wide and 90 m deep, containing 1.47 percent Cu and 0.02 ounce of Au per ton. There appears to be less massive pyrite and pyrrhotite associated with this zone than with the Sonya Lake zone.

The **Peninsula zone**, which is perhaps the westward extension of the Discovery Lake zone, underlies the large peninsula in the north end of Lower Nistoassini Lake (Figures 17 and 20). The eastern portion is poorly exposed, but several trenches have been dug on the central portion and some massive sulphide is exposed at surface. Ground geophysics and diamond-drilling indicate mineralization widths of up to 120 m. Trench H1 (Table 15) was cut across this zone.

The **Kenwood River zone** extends from above the first rapids on the river southwards for several hundred metres and then swings easterly to the shore of Lower Nistoassini Lake, closely following the top of the felsic volcanic pile (Figures 17, 20 and 21). This zone continues intermittently along the contact between the felsic volcanics and the greywacke-argillite unit northward to Greenhill Lake. Exposures of 6 to 12 m of massive pyrrhotite-pyrite mineralization are common and drill intersections up to 30 m have been reported (Assessment File 64D04-NW-0013). Disseminated chalcopyrite occurs in the sulphide zone above the Kenwood River rapids.

The **South Nistoassini zone** extends westward from the southeastern bay of Lower Nistoassini Lake along the contact between the felsic volcanics and the greywacke-argillite unit, and then swings southwest, following the contact between the felsic volcanics and a feldspar porphyry-quartz diorite intrusion. This zone has been drilled and trenched over a width of 10 to 30 m and has been found to contain pyrite-pyrrhotite nodules.

Economic Evaluation

When the economics of producing iron from barren massive sulphide deposits become more favourable, the Lower Nistoassini area may become an important source. The many deposits are exposed at surface and are amenable to open pit mining methods. Grades are variable, but the size of the deposits may permit mining even of the lower grade sections. A major highway only 16 km south of Lower Nistoassini Lake would eliminate any serious transportation problems.

Kirk Lake

The discovery of gold and massive sulphide mineralization in the Waddy Lake area as early as 1928 (Byers, 1948) stimulated exploration in the area. Numerous zones of disseminated to massive but barren iron sulphide mineralization were discovered in the vicinity of Kirk Lake, 16 km west of Waddy Lake (Miller, 1949). Reports from drill

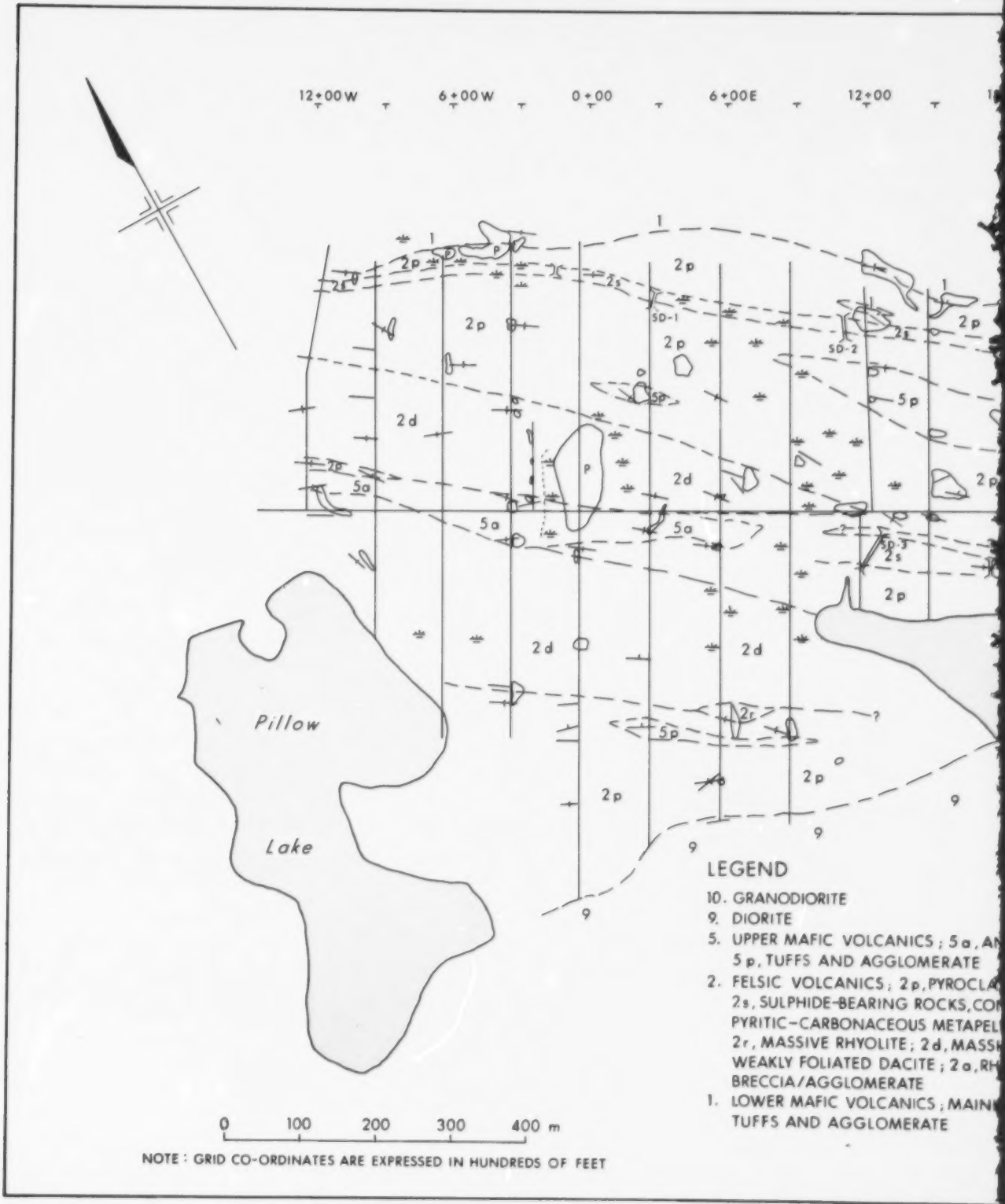
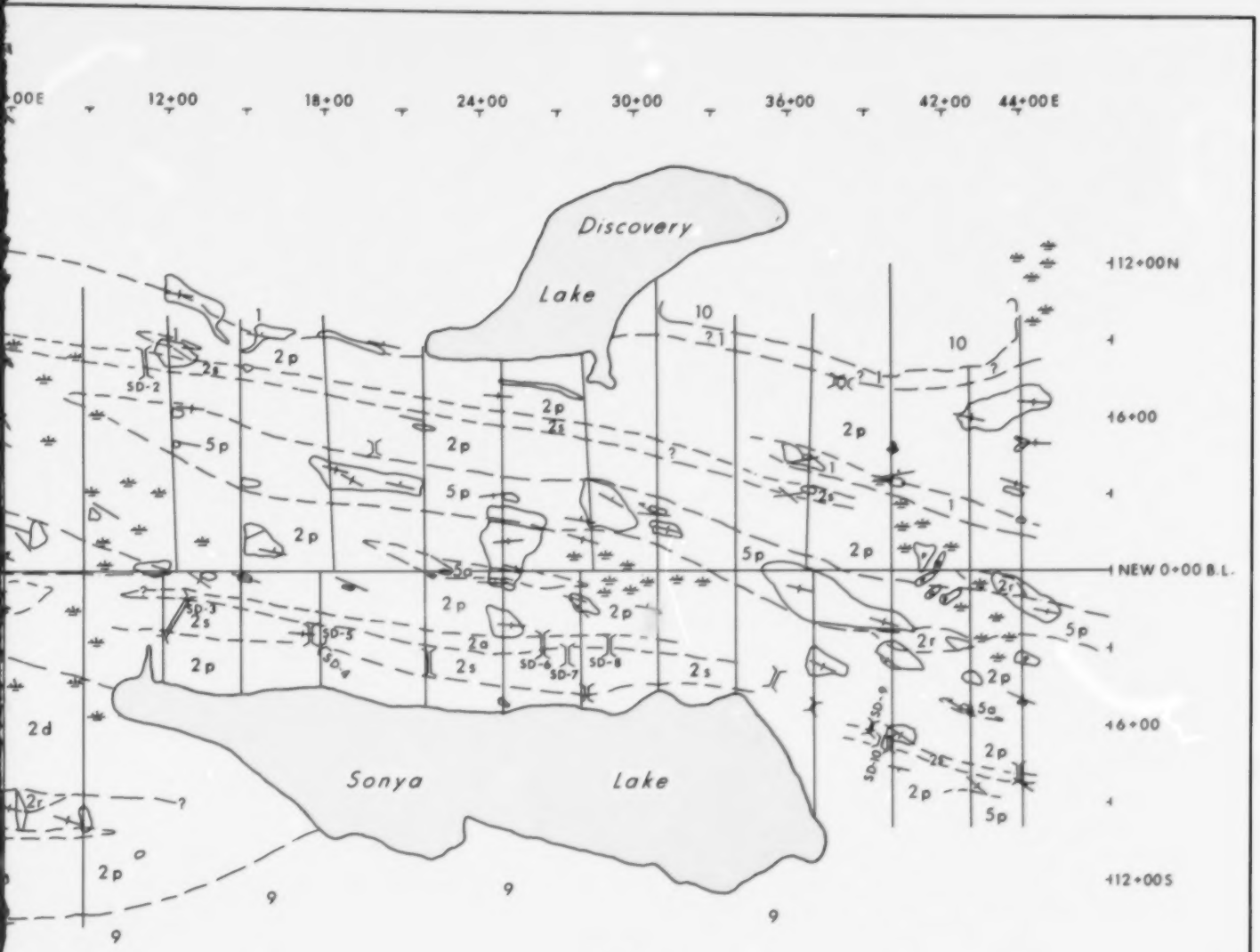


Figure 19. *Geology of the Sonya Lake and Discovery Lake zones, Nistoassini Lakes area. Rock unit numbers correspond to*



EGEND

. GRANODIORITE
DIORITE
UPPER MAFIC VOLCANICS; 5a, ANDESITE; 5p, TUFFS AND AGGLOMERATE
FELSIC VOLCANICS; 2p, PYROCLASTICS; 2s, SULPHIDE-BEARING ROCKS, CONTAINING PYRITIC-CARBONACEOUS METAPELITES; 2r, MASSIVE RHYOLITE; 2d, MASSIVE OR WEAKLY FOLIATED DACITE; 2a, RHYOLITE BRECCIA/AGGLOMERATE
LOWER MAFIC VOLCANICS; MAINLY PYROCLASTICS, TUFFS AND AGGLOMERATE

SYMBOLS

GEOLOGICAL CONTACTS
AREA OF OUTCROP
BEDDING AND FLOW LAYERING (INCLINED, VERTICAL, DIP UNKNOWN)
SD-5 TRENCH, NUMBER REFERRED TO IN TEXT
P POND
MUSKEG
CUT BASE LINE AND FLAGGED CROSS LINES

. Rock unit numbers correspond to those in Figure 17. Compiled from field work by the author (Harper, 1974) and Billingsley (Harper, 1976).

LEGEND

	IRON CEMENTED TILLITE
	UNCONFORMITY
10	GRANODIORITE
8	MAFIC INTRUSIONS
5	UPPER MAFIC VOLCANICS, MAINLY TUFFACEOUS
3s	SULPHIDE ZONE CONTAINING ACID VOLCANICS
3a	PYRITIC-CARBONACEOUS METASEDIMENTS
3	GREYWACKE / ARGILLITE
2a	RHYOLITIC AGGLOMERATE
2	FELSIC VOLCANICS : ACIDIC TUFF AND RHYOLITE

SYMBOLS

GEOLOGICAL BOUNDARIES (DEFINED, ASSUMED)

AREA OF OUTCROP

BEDDING / FLOW LAYERING (INCLINED, VERTICAL, DIP UNKNOWN)

ESCARPMENT

GOSSAN IN SOIL — G

TRENCH (OLD, EXCAVATED 1974) — H7

INCLINED DIAMOND DRILL HOLE — VET #2

LOW GROUND AND MUSKEG

PICKET LINES

"CAT" TRAIL

MINERALIZATION (PYRITE, PYRRHOTITE, CHALCOPYRITE, GRAPHITE) — py, po, cp, gr

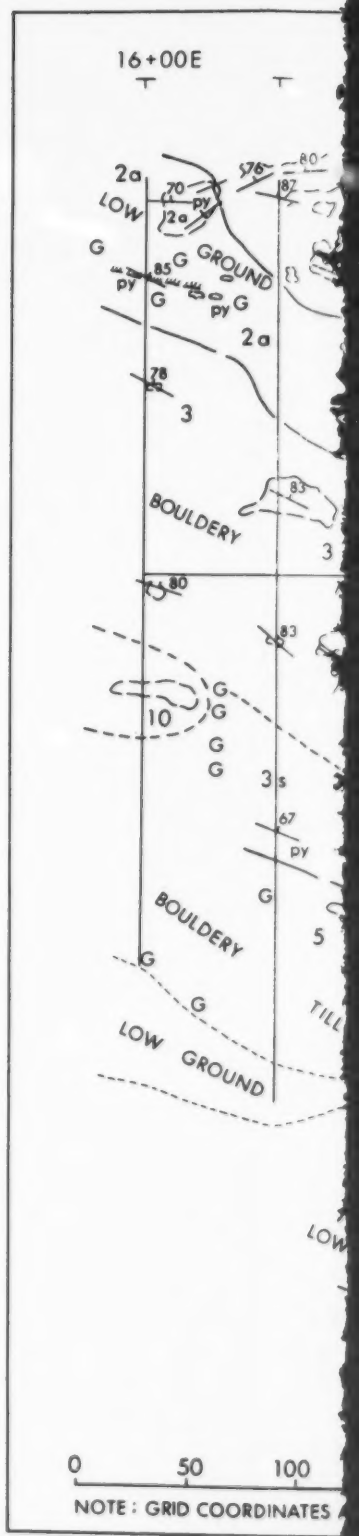
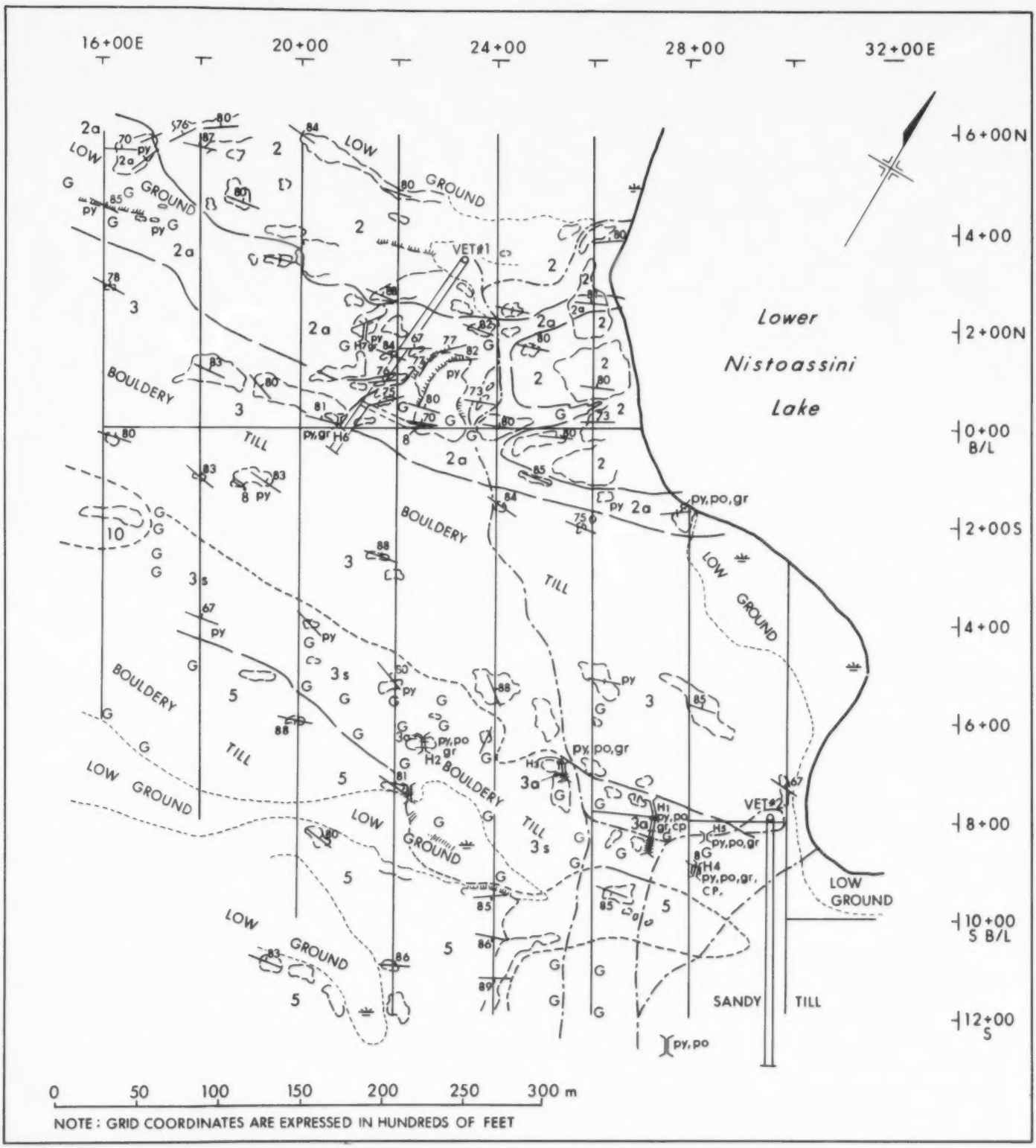


Figure 20. *Geology of parts of the Peninsula and Kenwood River zones, Nistoassini Lakes area. Rock unit numbers corres*



Lakes area. Rock unit numbers correspond to those in Figure 17. Compiled from field work by the author (Harper, 1974).

LEGEND

2	FELSIC VOLCANICS	3	GREYWACKE/ARGILLITE
2a	RHYOLITIC BRECCIA/AGGLOMERATE	3a	WITH STAUROLITE AND GARNET
2r	RHYOLITE	3b	MAFIC VOLCANICS

SYMBOLS

GEOLOGICAL BOUNDARY

AREA OF OUTCROP

SCHISTOSITY (INCLINED, VERTICAL) 20

TRENCH

GOSSAN IN SOIL G

PYRITE, PYRRHOTITE, GRAPHITE, CHALCOPYRITE py, po, gr, cp

SULPHIDE MINERALIZATION (MASSIVE, STRONG TO WEAKLY DISSEMINATED)

INCLINED DIAMOND DRILL HOLE AND NUMBER WIN #16

MUSKEG

PICKET LINES 43+00

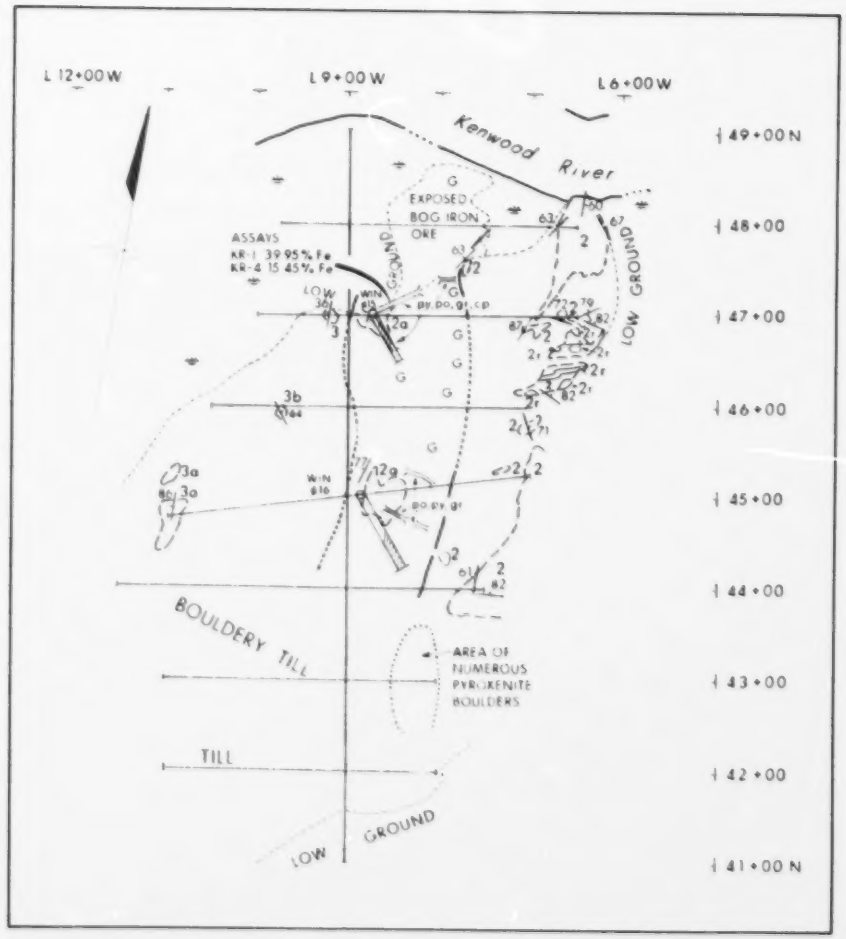


Figure 21. *Geology of part of the Kenwood River zone, Nistoassini Lakes area. Rock unit numbers correspond to those in Figure 17.*

intersections of massive sulphides more than 20 m thick prompted a detailed examination of several zones (Harper, 1974).

Geology

The Kirk Lake area is characterized by low relief (generally less than 10 m), extensive areas of muskeg and a thin but widespread glacial cover. Bedrock exposure is poor. The general geology of the area is shown in Figure 22. The barren massive sulphides are associated with Precambrian mafic metavolcanics, and minor felsic volcanics and pyritic carbonaceous rocks. Pleistocene (pre-Wisconsin, Johnston, 1971) iron-cemented tills and bog iron ores are closely associated with the sulphide zones. Except for fault-related drag folding, the structure is fairly simple. The rocks trend north-northeast along Kirk Lake but trend easterly north of the lake.

Rock Descriptions

The **mafic metavolcanics** are generally poorly foliated, light to dark grey-green, fine grained and of basaltic to andesitic composition. Tuffaceous varieties and coarser pyroclastics are present. Closely spaced fracturing is a common feature. Hornblende metacrysts (up to 1 cm in size) and garnet porphyroblasts occur locally.

Although **felsic volcanics and carbonaceous rocks** form only a small proportion of the exposed bedrock, they are almost everywhere associated with massive sulphide occurrences. The coarse-grained felsic volcanics are white, commonly limonite stained, and normally occur as flows and/or tuffs forming lensoid bodies up to 60 m thick and several hundred metres long. The pyritic-carbonaceous rocks are typically iron stained, light grey to black, fine grained and finely laminated. They contain disseminated, layered and massive iron sulphides. Pyrite is common in the first two types, while pyrrhotite is common in the massive iron sulphides.

Limonite-goethite-cemented till forms a well-indurated crust above many sulphide occurrences. In swampy areas, these deposits either form crumbly encrustations around uncemented till or replace organic debris (**bog iron ore**). Their presence is often the only indication of the sulphide zone beneath.

Structure and Metamorphism

No primary volcanic or sedimentary structures other than bedding were observed. A metamorphic foliation parallels the original layering. Although no major folds were found, some warping and fault-related drag folding were observed. A major fault with several parallel subsidiary faults, trending northward through Kirk Lake, changed the regional trend by at least 90° on the west side of Kirk Lake. A right lateral movement is indicated by the drag folding. The area underwent Barrovian-type metamorphism, with peak conditions in the middle amphibolite facies.

Geochemistry

Twelve composite chip samples collected from two trenches near the north end of Kirk Lake indicate a mineralized zone at least 8.3 m in width containing 27.65 percent Fe. The zone is 360 m long and has a maximum width of 60 m.

Economic Geology and Evaluation

Sulphide mineralization is similar in composition and texture to that described for the Nistoassini Lakes area. It consists of disseminated, massive and banded pyrite and pyrrhotite, as well as minor disseminated chalcopyrite. Drilling has revealed that most of the electromagnetic conductors contain barren sulphide mineralization. Four mineralized zones, chosen for examination on the basis of drill intersections, are now discussed briefly.

The **North zone**, located about 1 km north of Kirk Lake, trends easterly for 1 km and then swings toward the north end of Kirk Lake (Figure 22). Although adequate surface exposures were not found, the zone, which is partially indicated by gossanous soils and rusty sulphurous-smelling muskeg pools, is about 60 m wide and has been evaluated from six diamond-drill holes (Assessment Files 74A01-NE-0002, 0003 and 0031) and at least four trenches. The zone may have been thickened by drag folding along the major north-south fault. No iron assays are available.

The **Central zone** occupies a swampy area between two bays on the west side of Kirk Lake (Figure 22). It is at least 360 m long and 60 m wide. Several strongly limonite-stained outcrops of pyritic carbonaceous schist occur along the edges of the zone. Six trenches, two of which were sampled, expose the mineralization at the north end. One diamond-drill hole (Assessment Files 74A01-NE-0002 and 0003) intersected a cumulative total of 35 m of massive sulphide, including one continuous section of 26 m. Although not representative of the entire zone, the northern section gave 27.61 percent Fe across 8.3 m.

The **West zone** occurs along the western edge of and in a large muskeg patch about 1 km west of Kirk Lake (Figure 22). Three diamond-drill holes and several old trenches have tested the zone along a 1 km length, but the iron content is not known.

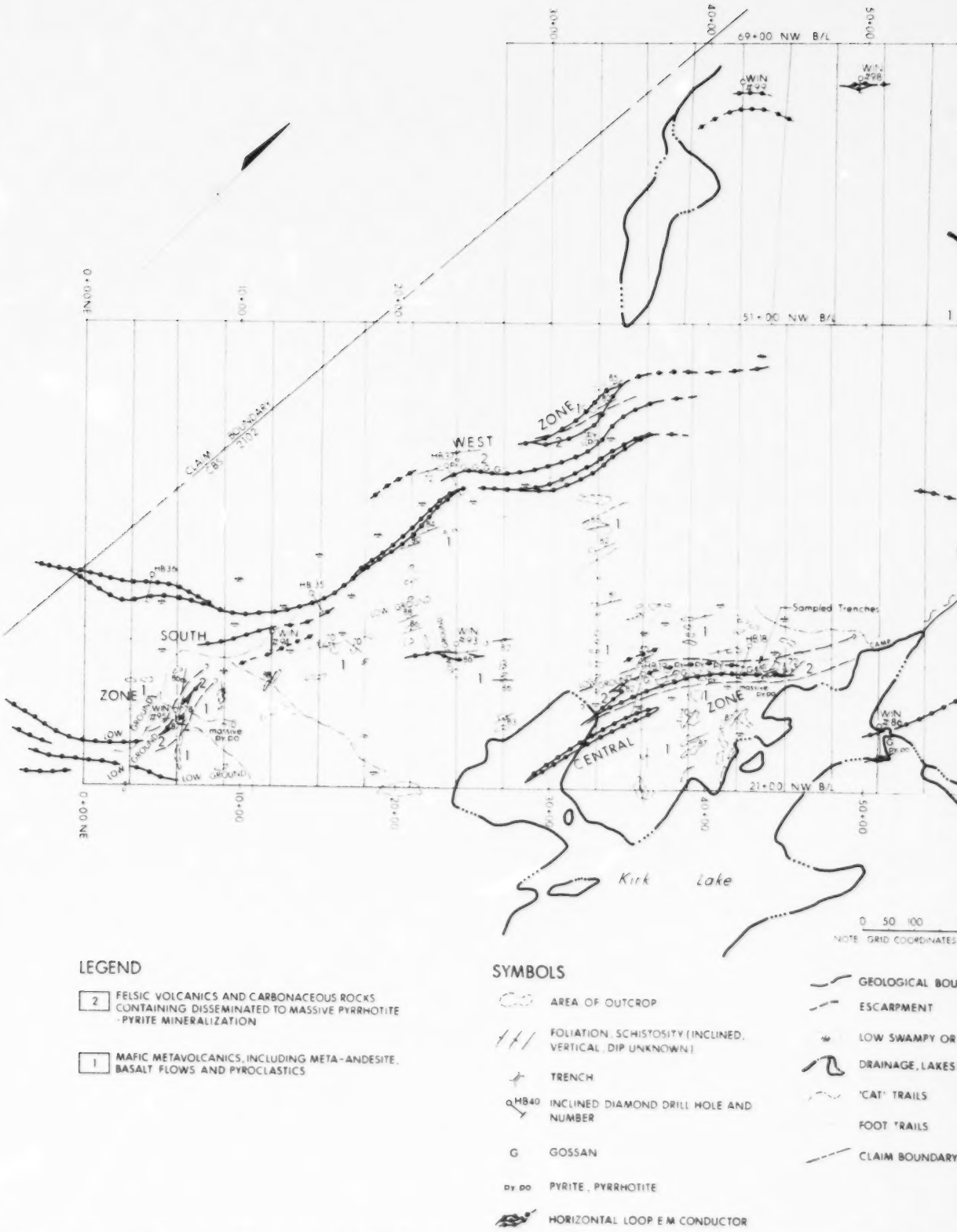
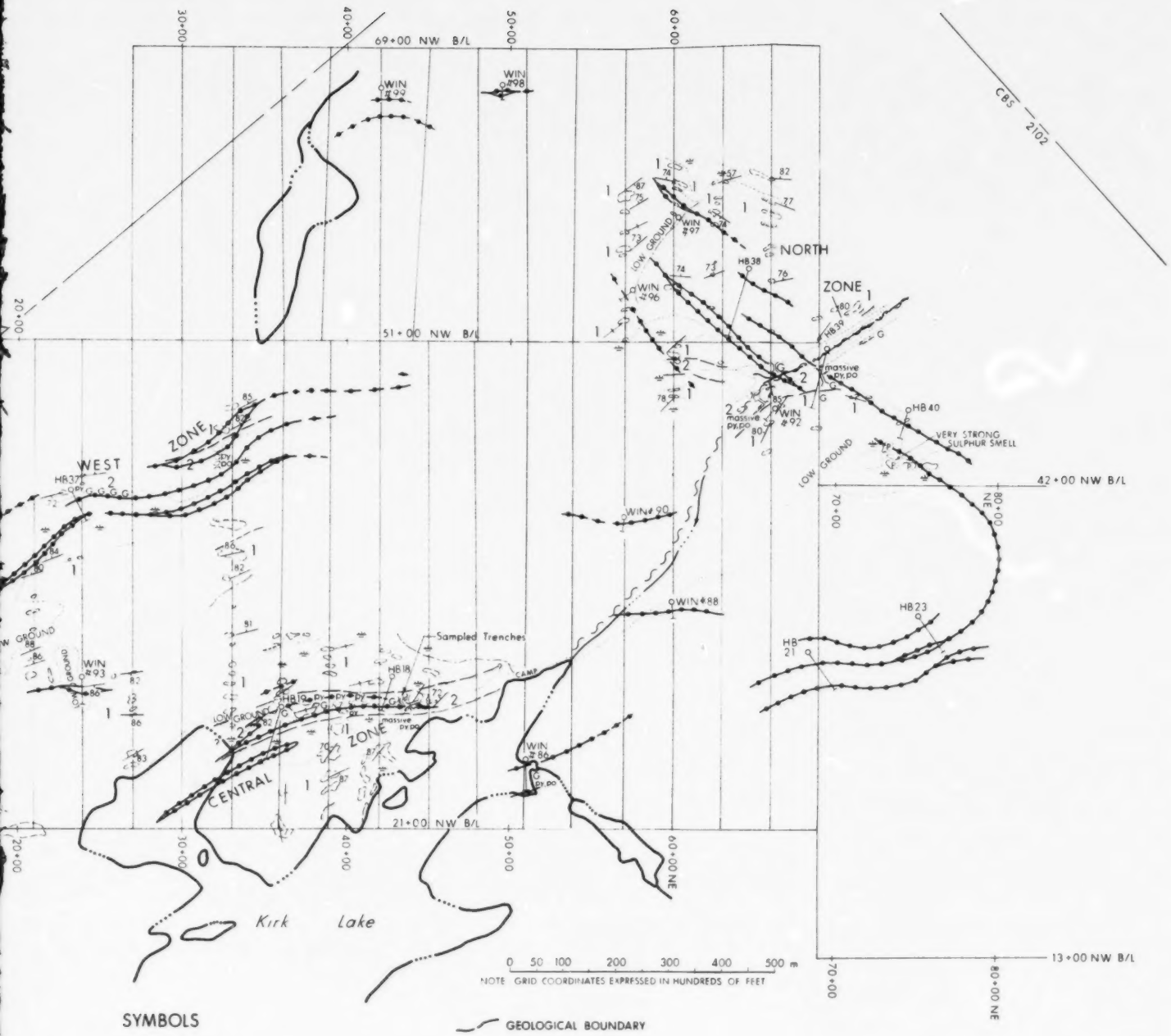


Figure 22. *Geology of part of the area west of Kirk Lake. Compiled from field work by the author (Harper, 1974) and asses*



SYMBOLS

- AREA OF OUTCROP
- FOLIATION, SCHISTOSITY (INCLINED, VERTICAL, DIP UNKNOWN)
- TRENCH
- HB40 INCLINED DIAMOND DRILL HOLE AND NUMBER
- G GOSSAN
- py, po PYRITE, PYRRHOTITE
- HORIZONTAL LOOP E M CONDUCTOR
- GEOLOGICAL BOUNDARY
- ESCARPMENT
- LOW SWAMPY OR MUSKEG AREAS
- DRAINAGE, LAKES OR PONDS (P)
- 'CAT' TRAILS
- FOOT TRAILS
- CLAIM BOUNDARY

rk Lake. Compiled from field work by the author (Harper, 1974) and assessment work data submitted to Saskatchewan Energy and Mines.

The **South zone**, located about 600 m southwest of the large western bay of Kirk Lake (Figure 22), is marked by a short discontinuous conductor which has been drilled (Assessment File 74A01-NE-0031). Barren sulphide mineralization, which outcrops 9 to 12 m from the drill collar, strikes almost parallel to the azimuth of the hole. Thus, a much exaggerated intersection was obtained when in fact the zone was only 3 to 6 m thick at surface.

The barren massive sulphide deposits near Kirk Lake, although not as well exposed as those in the Nistoassini Lakes area, have similar host rocks. These zones are not too far from existing roads, and together contain sufficient iron to be of economic interest, apart from the high percentage of sulphur.

Forbes Lake

Numerous barren massive sulphide deposits have been reported from the Forbes Lake area (Pearson and Froese, 1959; Beck, 1959). The sulphide zone between Bateman Lake and the northeast end of Forbes Lake (Figure 23) was chosen for detailed study (Table 1).

Geology

Forbes Lake lies close to the contact between metamorphosed sedimentary and volcanic rocks of the La Ronge Domain. Mafic to intermediate volcanics with minor volcaniclastics and felsic volcanics lie to the southeast, while sediments associated with minor volcanics occur to the northwest. Both sediments and volcanics are intruded by ovoid granitic plutons. Most of the sulphide zones are associated with pyritic-carbonaceous (graphitic) shales and/or calc-silicates. Iron-cemented tills and recent bog iron ores are intimately associated with the sulphide zones. The geology of the area studied is shown in Figure 23.

The area examined, measuring about 3.4 km long by 500 m wide, is centred on a northeast-trending sulphide-metavolcanic zone flanked to the northwest and southeast by metasedimentary gneisses (Figure 23). The sulphides, mainly pyrite and pyrrhotite with minor disseminations of chalcopyrite and sphalerite, are hosted by carbonaceous and/or graphitic shales, argillites, felsic tuffs and flows, and calc-silicates. The volcanics lying to the southeast of the main sulphide zone include mafic to felsic tuffs, agglomerates and minor flows, and minor calc-silicate interlayers. The metasediments include psammitic, semipelitic and pelitic rocks; carbonates are present on the northwestern side of the sulphide zone.

The lack of primary volcanic and sedimentary structures makes it difficult to work out the detailed stratigraphy.

Rock Descriptions

Metasedimentary gneisses outcrop along the southeast edge of the area. They are well layered and foliated, light to dark grey on both fresh and weathered surfaces, and vary in grain size from 2 to 3 mm. Layers are 0.1 to 5 cm thick and are most prominently developed where mafic minerals are abundant. Psammitic varieties tend to be less distinctly layered. Pegmatite veins increase in abundance to the southeast. The dominant metasediment to the northwest is a grey-weathering (dark grey on fresh surfaces), coarse-grained (3 to 4 mm grain size) gneissic metapelite which contains considerable pegmatitic (both intrusive and segregation) material. A coarse-grained (4 to 5 mm) dark grey-brown biotite (40 percent) gneiss lies close to the sulphide zone. This is overlain by a thinly layered, pale green to greenish-grey, coarse-grained calc-silicate/carbonate rock which contains 1 to 2 percent disseminated pyrite. Similar carbonate/calc-silicate rocks were intersected in three of the diamond-drill holes completed during this project.

Mafic volcanics and calc-silicates form a band up to 150 m thick to the southeast of the sulphide zone. They are commonly light to dark green to greenish-black on both fresh and weathered surfaces, well layered (0.1 to 10 cm) and medium to coarse grained. Where felsic material is abundant, the rock takes on a striped appearance. The volcanics consist of mafic tuffs and agglomerate, commonly calcareous, which are interlayered with the calc-silicate rocks. Felsic and mafic clasts in the agglomerate are so strongly stretched that in places they simulate layering. The maximum size of the clasts is about 20 cm long by 5 cm wide. The felsic clasts commonly resist erosion and stand out in relief. Some basic flows or intrusions are also present. These tend to be coarse-grained, massive, dark green, pyroxene-bearing rocks. The largest body is at least 60 m long and about 10 m wide. A few fine-grained, pink to white felsic flows or dykes up to 3 m thick occur locally.

The **sulphide-bearing zone** contains a variety of rocks but is dominated by a banded pyritic carbonaceous (graphitic) siliceous shale. This fine-grained rock weathers easily to a vuggy grey, yellow, orange or black fissile schist (quartz-sericite-pyrite-graphite schist). Layering is typically about 5 mm thick. Rocks from the drill core are finely laminated carbonaceous pyrite- (and pyrrhotite-) bearing felsic tuffs and silty sediments. Other rocks in this zone include iron-stained biotitic quartzite

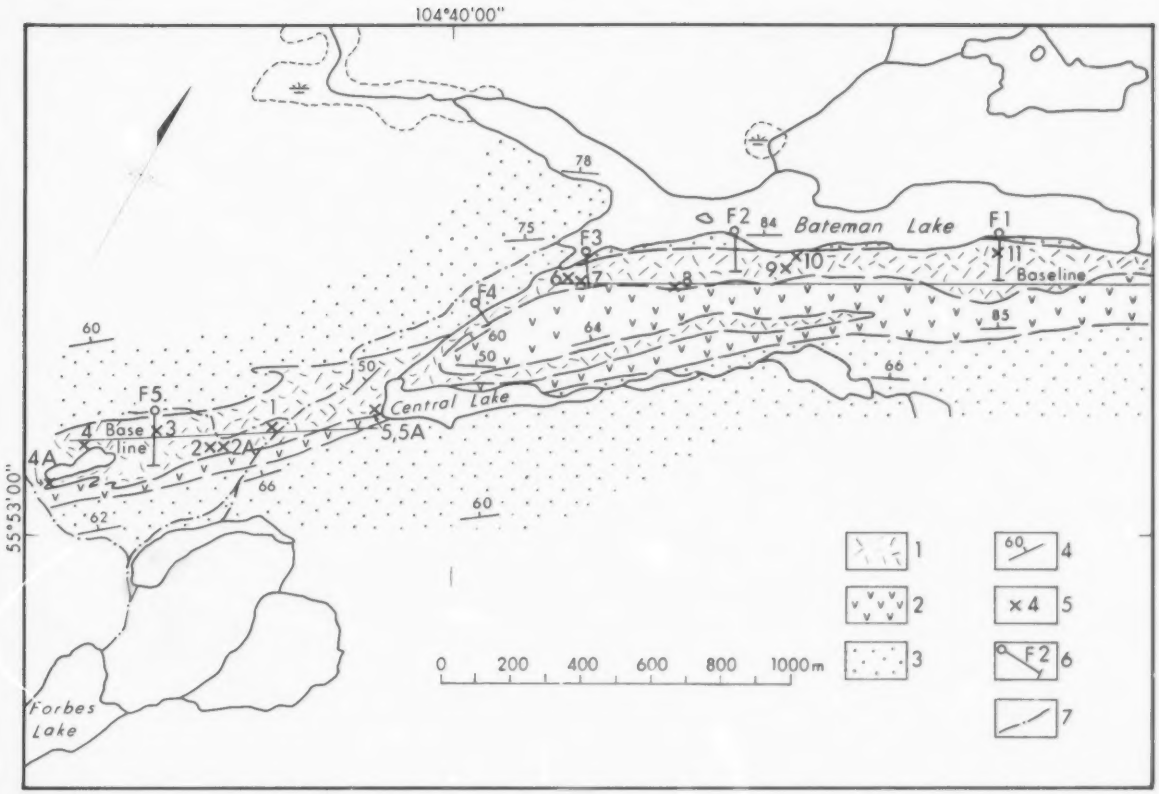


Figure 23. *General geology of the area between Forbes and Bateman Lakes, showing locations of trenches and diamond-drill holes completed during this study. Compiled from field work by the author (Harper 1975, 1976). 1, sulphide-bearing rocks; 2, intermediate to mafic metavolcanics and minor calc-silicates; 3, metasedimentary gneisses; 4, foliation (inclined); 5, trench; 6, inclined diamond-drill hole; 7, drill trail/portage.*

and/or arkose, and rhyolites. The rhyolites are light to dark grey, fine to coarse grained, poorly to well foliated, and normally contain less than 3 percent pyrite. Pale green calc-silicate rocks, present locally, typically contain a few percent disseminated pyrite. The massive pyrite-pyrrhotite zones are most commonly associated with the carbonaceous tuffs and shales.

Iron-cemented till and bog iron ore are prevalent along the length of the sulphide zone and in places downslope, particularly at water seeps. The bog iron ores, composed of friable granular to nodular concentrations of limonite-goethite, replace both organic remains and some of the rock fragments (Plate 20). Shallow rusty-bottomed sulphurous pools are normally associated with these deposits.

Structure and Metamorphism

Examination of regional airphoto lineations and airborne magnetic and electromagnetic surveys (Geological Survey of Canada, 1966a; Assessment Files 73P15-0017 and 73P15-NE-0033) suggests that the area mapped lies along the northwest limb of a larger overturned synform that has a northeasterly trending axial plane and a steep northwesterly dip. Layering and metamorphic foliation in the map area trend northeast, but there is some deflection along the river joining Bateman Lake and Central Lake[1]. An isoclinal fold closure with a 'tuning fork' shape is outlined by the sulphide zone and appears to be plunging 50 to 60° northwest. Small-scale folds are rare and of little help in defining large-scale structures.

A possible north-northeasterly striking fault is suggested by the linearity of the stream draining Bateman Lake. Apparent offsets of rock units and 3 m of unrecovered core from a hole drilled directly beneath the river support the presence of the fault. Some sulphide mobilization appears to have occurred into and along the fault.

The metamorphism that accompanied the regional deformation reached middle to upper amphibolite

[1]Unofficial name.

grade and was apparently higher grade to the northwest. A penetrative foliation lies parallel to the layering and is most strongly developed in the northwestern sediments.

Sulphide Mineralization

There are five types of iron sulphide mineralization in the Forbes Lake area: 1) brecciated, 2) bedded, 3) remobilized, 4) veined, and 5) disseminated. Although disseminations of chalcopyrite and sphalerite are present, they are so few that they will not be discussed.

Breccia mineralization is the most important type. Varying in thickness from 15 to 30 m, the sections contain felsic volcanic and carbonaceous shale clasts, as well as some sulphide clasts, set in a matrix of massive pyrrhotite and some pyrite. The clasts vary in size from small specks to boulders tens of centimetres across. Angular to well rounded in places, they are slickensided and folded. Pyrrhotite is normally coarse grained, crystalline and structureless, although flow lines are present in some areas. In places, massive pyrrhotite contains up to 30 percent euhedral pyrite cubes measuring as much as 1 cm across. Sections of massive pyrite having the same characteristics as the pyrrhotite also occur.

Bedded sulphide mineralization, or "sulphide facies iron formation", includes pyrite, pyrite-pyrrhotite and less commonly pyrrhotite in layers 1 to 4 mm thick, alternating with layers of carbonaceous shale and felsic tuff of comparable thickness. Pyrite is typically euhedral. Sulphides generally comprise 10 to 30 percent of the rock and can reach as much as 60 percent in places.

Remobilized sulphides represent recrystallization of earlier sulphide mineralization in low pressure areas such as boudin necks, open fractures and other voids caused by brecciation during deformation. Coarse-grained sphalerite is commonly found in remobilized pyrrhotite occupying fractures in felsic volcanic fragments.

Veins consisting of pyrite and pyrrhotite are generally less than 5 cm thick and are later than all structures and other types of mineralization. Their association with alteration haloes suggests they are related to a later hydrothermal event.

Disseminated pyrite and pyrrhotite occur in most of the rocks but are generally insignificant, amounting to less than 2 percent by volume.

Layered massive iron sulphide lenses, interbedded with black carbonaceous shales associated with volcanic rocks, have been described from numerous localites and attributed to volcanogenic processes (Hutchinson, 1973; Jenks, 1975). This same rock association is observed in the Forbes Lake area, but the general brecciated condition of the sulphides is not so readily explained. Several possible causes exist, such as faulting, replacement phenomena, explosive volcanic activity or large-scale slumping. Brecciation due to faulting and subsequent replacement along fractures may be important locally, but this does not explain all observed features.

The sulphide-bearing zone is characterized by an interlayering of finely laminated banded pyritic and carbonaceous felsic tuffs and shales, together with lenses of massive sulphides, rhyolites and other minor sedimentary components. In places, the tuffs and shales are totally disrupted and display penecontemporaneous folds, rip-up structures, deformed clasts and a chaotic arrangement of clasts. The sulphide matrix has in places a flow-banded texture along and around fragments, and commonly contains fragments of rhyolite, felsic tuff and carbonaceous shales.

The presence of tuffaceous volcanics and a few exotic rhyolite fragments in the sulphides suggests that explosive volcanism occurred in the region. Such explosive activity could have triggered large slumps on steeply inclined submarine slopes. The breccia mineralization occurs along the entire length of the sulphide zone and consequently the features described above are interpreted by the author as slump features. Rupke (1976) described slump sheets from the southwestern Pyrenees which are as long or longer than the sulphide zone examined here. He also observed deformed clasts, flow banding, rip-ups, penecontemporaneous folds and a chaotic arrangement of clasts, all analogous to the features observed here. The Forbes Lake barren massive sulphides are attributed to volcanogenic processes and, although they may have been modified by a number of events, the brecciated character is probably the result of large-scale slumping, perhaps due to nearby explosive volcanism.

Geochemistry

Soil samples were collected for geochemical analysis from the Bateman Lake and Central Lake grids. An excellent correlation between the mineralized zones and 'high background' to 'anomalous' values for Fe, Cu and Zn can probably be attributed to the relatively thin soil cover and flat-lying nature of the area. Exceptions to this are classic down-slope anomalies obtained from the southeast side of the Central Lake grid where the mineralized zone is bounded by a steep

southeasterly facing slope. Several single station anomalies, usually located in muskeg, were encountered some distance from the mineralized zones, but little significance is attached to them.

Of the 109 rock chip samples collected, 99 are composite samples from trenches excavated in 1975 (Harper, 1975b) and the remainder are grab samples. The composite samples were assayed for Fe, Cu and Zn; 21 of these from trenches 3 and 4A (Figure 23) were also assayed for gold. Some of the low iron values shown in Table 16 reflect the weathered nature of the material, since it was difficult to obtain fresh rock samples in many of the trenches. Massive pyrrhotite samples generally contain 30 to 40 percent Fe; the maximum value is 47.3 percent over a 1.33 m length. Copper and zinc are low, averaging 0.02 and 0.05 percent respectively. Only traces of gold were detected in the two trenches tested. Trenches 4A and 11, which were excavated along the strike of the sulphide zones, gave somewhat higher averages. The considerable variation in iron content along strike is caused primarily by variation in the amount of exotic clasts (felsic volcanic and carbonaceous schist) present.

Three grab samples of iron-cemented till and bog iron ore yielded average compositions of 43.7 percent Fe, slightly above the values obtained from the massive sulphides (Table 17). Iron-cemented till from the last 2.7 m of trench 9 gave higher assays than the sulphide-hosted rocks.

Five inclined diamond-drill holes, totalling 808.6 m, were located along the sulphide trend: three along Bateman Lake, the fourth between Bateman and Central Lakes, and the fifth 660 m southwest of Central Lake (Figures 23 and 24). The elements Fe, Cu, Zn and Au were assayed, along with Ni and C from some of the cores (Table 18). The highest value was obtained from hole F4, where a 25.4 m section yielded 31.68 percent Fe and a 12.7 m section of this yielded 38.66 percent Fe. A 27.1 m section of bedded pyritic-carbonaceous shale and tuff in hole F1 yielded 13.65 percent Fe and 5.13 percent C. Values obtained for Cu, Zn, Ni and Au were all insignificant.

Table 16. Summary of Trench Assays, Central Lake and Bateman Lake Grids, Forbes Lake Area

Trench Number	Length (m)	Average Values (percent) Fe	Cu	Zn	Au
Central Lake Grid:					
1	10.5	10.49	0.01	0.05	-
2	20.4	8.68[1]	0.01	0.05	-
2A	5.5	9.10	0.01	0.05	-
3	14.6	8.54	0.02	0.07	tr
4	12.6	12.9	0.02	0.05	-
4A	3.0[2]	43.5	0.045	0.225	tr
	10.8[3]	38.24	0.044	0.315	tr
5	13.5	16.11	0.02	0.05	-
5A	6.0	15.63	0.02	0.05	-
Bateman Lake Grid:					
6	11.5	17.86	0.02	<0.05	-
7	5.5	15.86	0.016	<0.05	-
8	4.5	31.87	0.023	<0.05	-
9	10.0	26.05	0.02	<0.05	-
10	13.0	14.11	0.017	<0.05	-
11	8.7	36.57	0.03	0.06	-

[1]average of only 9 m
[2]across strike
[3]along strike
tr = trace
- = not analyzed

Economic Considerations

Barren massive iron sulphide deposits, bedded pyritic shales and tuffs, iron-enriched tills and bog iron ores in the Forbes Lake area all contain commercial grades of iron. Although the massive zones vary considerably in thickness (from less than 1 m to greater than 30 m) as well as in depth and lateral continuity, the zone of sulphide mineralization is continuous for a strike length of at least 5 km and widths of up to 200 m. The deposits appear to be amenable to open pit mining and are within 15 km of a major highway. The low base metal content of most

Table 17. Assays of Grab Samples, Forbes Lake Area. All Values in Weight Percent Unless Otherwise Indicated

No.	Sample No.	Fe	Cu	Zn	Au[1]	Mn	Mg	Ti	Ag[1]
1	7511-F17A	25.60	0.04	0.10	tr	-	-	-	0.04
2	7511-F38C	15.05	0.03	0.05	0.005	-	-	-	0.06
3	7511-F39	17.45	0.01	<0.05	-	-	-	-	-
4	7511-F44B	25.65	0.05	0.05	tr	-	-	-	tr
5	7511-F45C	9.95	0.02	<0.05	-	-	-	-	-
6	7511-F50C	43.50	-	-	-	-	-	-	-
7	7511-F132A	39.4	-	-	-	0.01	0.90	0.08	-
8	7511-F132B	47.6	-	-	-	0.01	0.30	0.11	-

Samples 1 to 5 - massive to semimassive pyrrhotite-pyrite
6 to 8 - bog iron ore and iron-cemented tillite

[1]expressed in ounces per ton
tr = trace
- = not analyzed

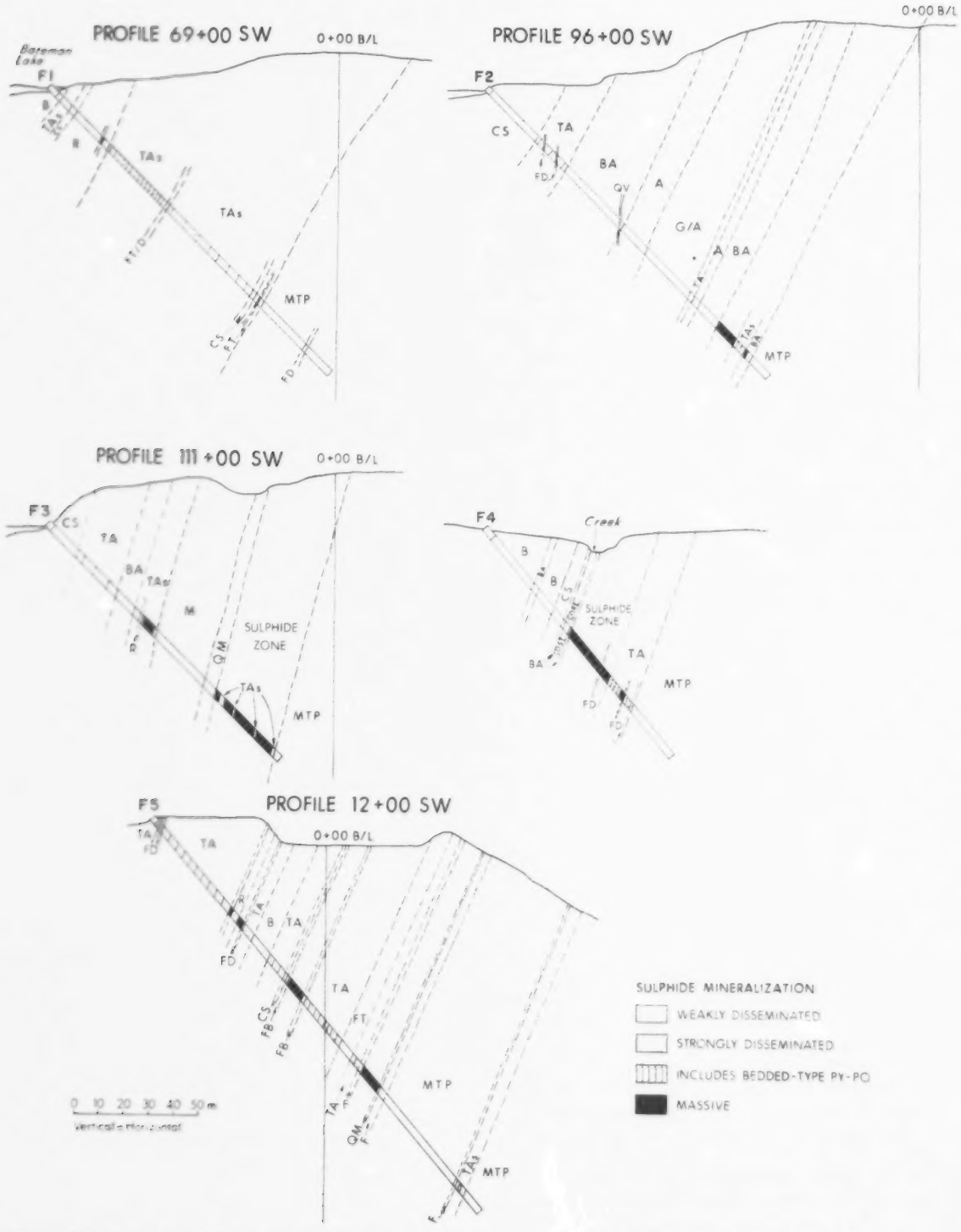


Figure 24. *Diamond-drill sections, Forbes Lake area (see Figure 23 for location of holes). MTP, mafic tuffs and pyroclastics; TA, carbonaceous tuffs and metapelites, also sulphide-bearing (S); R, rhyolite; CS, calc-silicate; B, biotite schist; F, felsite; FT, FD, FB, FT/D, felsic tuff, dyke, breccia and tuff/dyke; BA, biotitic meta-arkose; A, meta-arkose; GA, metagreywacke/meta-arkose; M, mica schist; QM, quartz-sericite schist; QV, quartz vein.*

Table 18. Assay Results from Diamond-Drill Core, Forbes Lake Area. All Values in Weight Percent Unless Otherwise Indicated

Hole	Interval (m)	Fe	Cu	Zn	Ni	Au[1]	C
F1	30.0-31.42	27.43	0.03	0.02	-	0.005	0.71
	33.5-60.8	13.65	0.02	0.06	-	0.005	5.13
F2	143.3-143.6	44.48	0.03	0.04	0.04	0.005	-
F3	100.0-131.1	16.20	-	0.03	-	0.002	-
F4	55.6-57.1	35.94	-	0.02	-	0.002	-
	57.6-59.7	35.64	-	0.03	-	0.002	-
	61.9-74.5	38.66	-	0.03	-	0.002	-
	75.6-80.8	34.13	-	0.02	-	0.002	-
	55.6-80.8	31.68					

[1]expressed in ounces per ton
- = not analyzed

of the sulphides should not cause any serious metallurgical problems. Despite the excellent potential of this area, the major drawback of the sulphide ores is their sulphur content.

Gossan Lake

Heavily iron-stained outcrops and soil gossans attracted attention to discontinuously exposed northeast-trending zones of sulphide mineralization in the central part of the Rottenstone Domain. Exploration of the area in 1959 and 1969 (Assessment Files 73P13-SE-0003 and 0006) revealed no significant base metal concentrations associated with the sulphides. However, during reconnaissance mapping of a portion of NTS area 73P, Ray (1974) noted the presence of disseminated to massive pyrrhotite-pyrite mineralization in the vicinity of Gossan Lake[1]. This prompted a re-examination of a 4.8 km long zone passing through the lake (Harper, 1975b).

Geology

The area is underlain by granitized biotitic felsic gneisses interlayered with iron sulphide-bearing quartzitic, graphitic and minor calcareous rocks (Figure 25). The rocks are tightly folded into a series of elongate northeast-trending overturned folds which have southeasterly dipping limbs and nearly horizontal but gently undulating axes. The principal mineralized zones occur in a synformal trough which follows the valley occupied by Narrow Lake.[1] The trough passes through the small peninsula at the west end of Gossan Lake and continues to the northeast. Limonite-goethite-cemented tills and bog iron ore are associated with the sulphide zones.

Rock Descriptions

Biotitic felsic gneisses, the dominant rocks of the area, weather rusty brown to grey and are light to dark grey on fresh surfaces. They are normally coarse grained and foliated, containing considerable segregation pegmatite. Locally they are garnetiferous. Few, if any, sulphides are found despite the common presence of iron stain.

Quartzitic (dominant), **graphitic and/or carbonaceous rocks** host the sulphide mineralization. They are commonly well-layered and -foliated rocks with moderate to strong limonite staining. Some of the quartzitic rocks are sericitic. Pyrrhotite and lesser amounts of pyrite occur as disseminations, fracture-fillings, irregular masses and massive pods or lenses within these rocks. A few greenish calcareous interlayers display thin layering and contain minor disseminations of pyrite.

One exposure of **iron-cemented till** overlying part of the sulphide zone measures 12 by 4 m and is at least 0.3 m thick. The till is cemented by limonite-goethite, which also replaces much of the organic material.

Origin of the Sulphide Mineralization

Although the high metamorphic grade and lack of primary depositional structures make interpretation difficult, the bulk of the rocks appear to be of sedimentary origin. The sulphides may have been precipitated under reducing conditions or, alternatively, they could represent distal exhalatives from a volcanic source.

Structure and Metamorphism

Ray (1974) recognized two generations of fold structure. The first (F_1), an isoclinal phase, was accompanied by the formation of a penetrative axial planar fabric and extensive migmatitic activity. The second period (F_2) produced isoclinal to open folds with steeply dipping, northeasterly-trending axial planes and variably plunging axes. In F_2 isoclinal

[1]Unofficial name.

[1]Unofficial name.

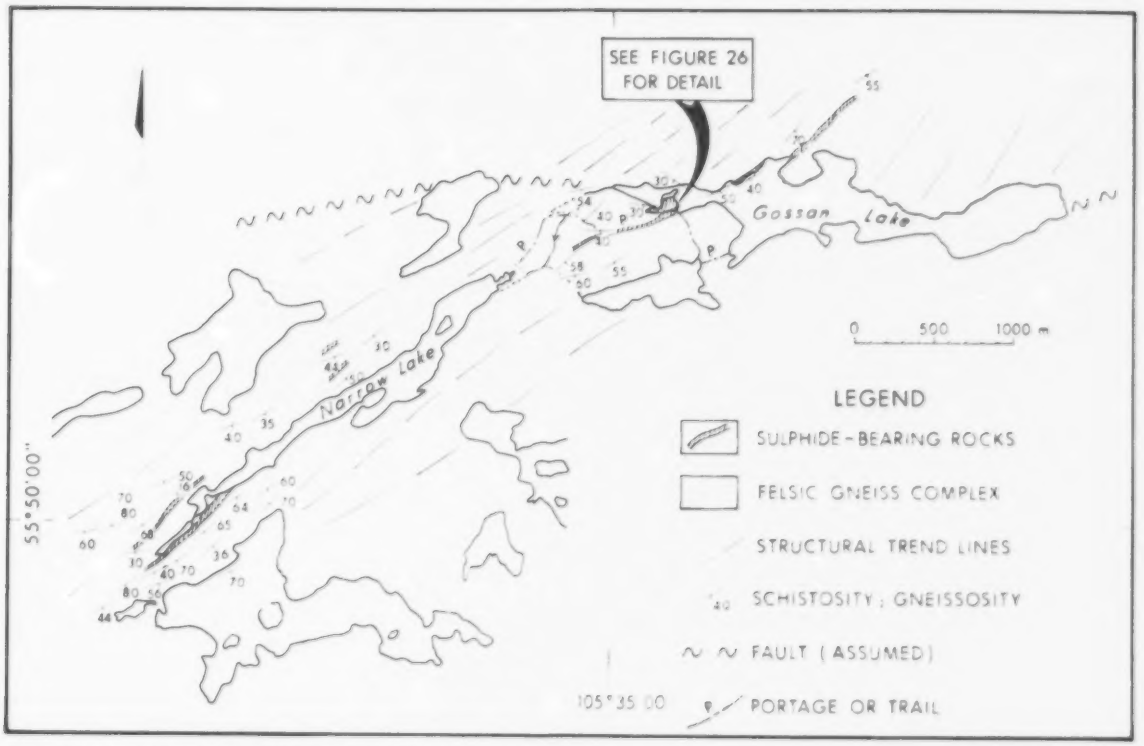


Figure 25. *Generalized geology of the Gossan Lake area. Compiled from field work by the author (Harper, 1975b) and Ray (1974).*

hinge zones, a younger foliation generally obliterates earlier fabrics.

Upper amphibolite facies and possibly granulite facies metamorphism (Ray, 1974) was accompanied by partial melting and extensive migmatization, presumably during F_2.

Geochemistry

In 1959, two diamond-drill holes totalling 30 m were drilled on the northwest shore of Narrow Lake (Figure 25). The holes intersected disseminated and massive pyrrhotite in felsic gneiss; assay values of 0.05 percent Cu and 0.05 percent Ni were obtained over 5.8 m (Assessment File 73P13-SE-0003). Similar values were obtained over 2 m in the second hole. In 1969, Tundra Holdings Company (Assessment File 73P13-SE-0006) had airborne electromagnetic and magnetic surveys flown over the area. The sulphide mineralization detected by this survey was sampled by blasting small test pits. Samples from eighteen pits excavated at the west end of Gossan Lake (Figure 26) gave average assay values of 0.02 percent Cu, 0.02 percent Ni and nil Mo. Samples taken from these same pits by the author gave soluble Fe values ranging from 1.75 to 21.9 percent and averaging 10.7 percent. Additional assays for Cu and Ni confirmed the earlier results and indicated an average value of 0.09 percent Zn. A single sample of the bog iron returned the following results (in percent):

Soluble Fe	*Al*	*Ca*	*Mg*	*Mn*	*Ti*	*Si*	*S*	*Moisture Content*
51.5	0.32	0.26	0.06	0.002	0.01	1.65	1.23	4.66 (100°C) 10.2 (220°C)

These results suggest that the bog iron ore has greater economic potential than the sulphide mineralization. However, the bog ores are generally limited in extent and thickness.

Lake sediment samples, collected by Ray in 1974 from Gossan and Narrow Lakes, were analyzed for Cu, Zn, Ni, Pb, Ag, Fe, Mn and loss-on-ignition by the Saskatchewan Research Council. Water depth was also recorded at each site. The results are presented in Figure 27 (in pocket) and a statistical summary is given in Table 19.

There is a positive correlation between depth and element abundance, and a notable lack of dispersion of values away from the sulphide zones. An exception is the shallow bay at the west end of Gossan Lake, where consistently high values were

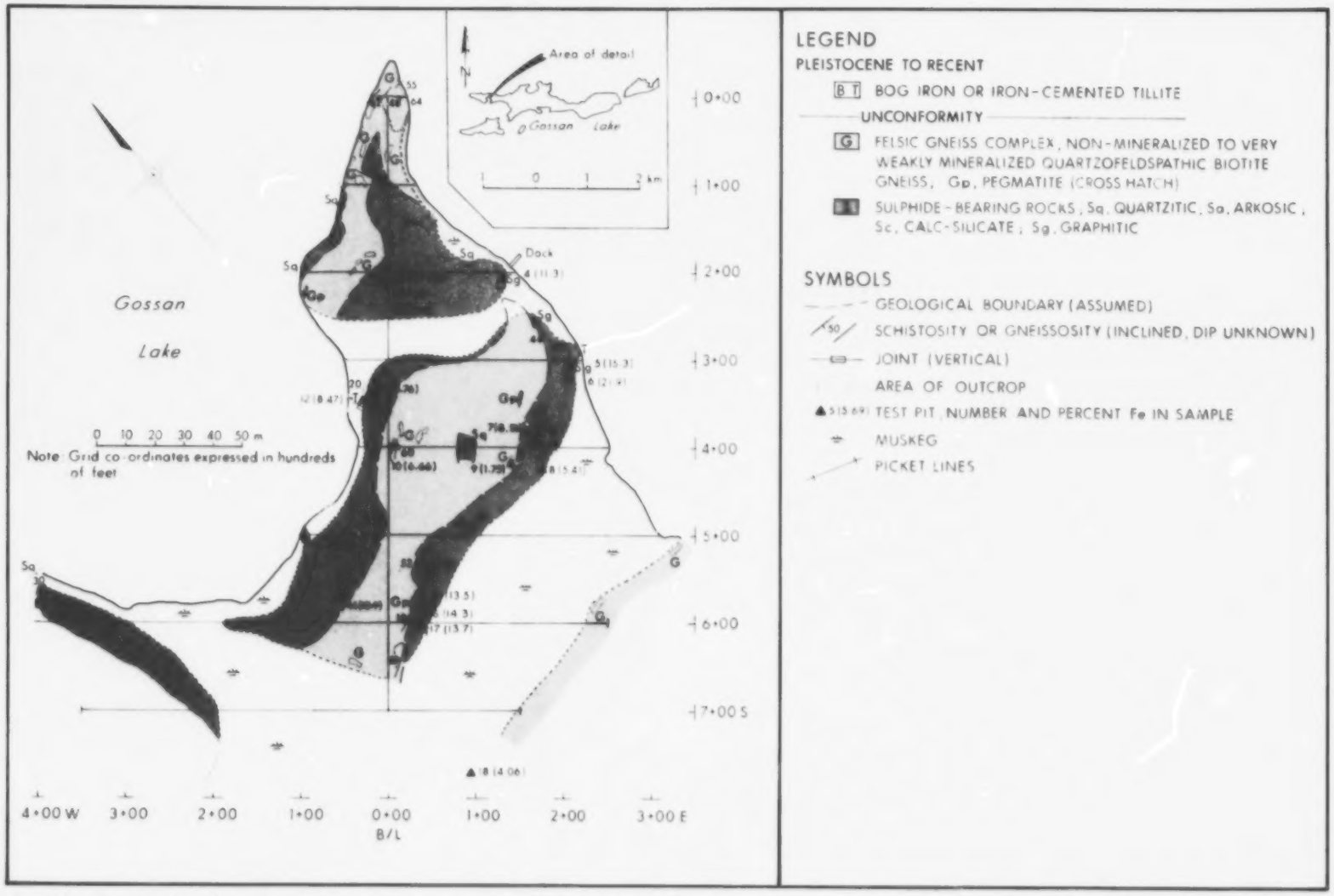


Figure 26. *Detailed geology of mineralized zone at Gossan Lake, showing location of test pits and assay results. Compiled from field work by the author (Harper, 1975b).*

Table 19. Statistical Summary of Lake Sediment Geochemical Results, Gossan Lake (46 samples) and Narrow Lake (32 samples). All Values in PPM Unless Otherwise Indicated

Parameter	*Cu*	*Zn*	*Ni*	*Pb*	*Fe*	*Mn*	*LOI*[2]
Min. Value	0/15[1]	31/16	5.0/27	0/5	8 000/12 000	0/0	2.4/3.5
Max. Value	79/67	770/600	152/89	35/30	157 000/104 000	4500/3210	55.8/90.5
Mean	34.8/41.5	2203/272	55.7/55.2	15.5/16.5	59 487/42 062	592.6/535.9	13.4/28.7
Standard Deviation	21.1/14.2	169.1/154.4	30.5/16.7	8.7/5.9	37 048/22 800	748.7/631.6	12.3/17.4
95th Percentile	75.0/63.0	630/480	109/82	32/23	140 000/78 000	1620/1590	36.4/42.6

[1]value for Gossan Lake/value for Narrow Lake

[2]expressed in percent

obtained. These values coincide with a sulphide zone and a rich bog iron ore.

Geophysics

A detailed ground magnetic survey was conducted on the main sulphide zone at Gossan Lake, with measurements recorded every 7.5 m along the base line and cross lines spaced 30 m apart. In areas of high magnetic values, a 7.5 m grid was used between the lines.

Background values are in the 59 000 to 60 000 gamma range. Values greater than 65 000 gammas are considered to be anomalous. Maximum values exceeded 100 000 gammas over areas 1 to 2 m in diameter. The survey revealed a complex distribution of pyrrhotite-pyrite mineralization, possibly indicating a tight refolded fold or the east-trending fault shown in Figure 26.

Economic Evaluation

Barren massive sulphides in the area are discontinuous, lack the size, thickness and grade to constitute an economic deposit, and in many places dip beneath a thick covering of biotitic felsic gneiss. Deposits of bog iron ore, although certainly of commercial grade, are too small to be of economic interest. The area is thus considered to have little potential as a source of iron.

Magmatic Type

Bassett Lake

A magnetite-bearing gabbroic complex with an associated aeromagnetic anomaly (Geological Survey of Canada, 1966b) was investigated for base metals between 1954 and 1968. Trenching and diamond-drilling indicated the presence of disseminated to massive pyrrhotite-pyrite mineralization accompanied by chalcopyrite and minor amounts of nickel, as well as magnetite mineralization. During the present investigation a study was made of an area surrounding Triangle Lake[1], a small triangular lake 1 km southeast of Bassett Lake (Figure 28), where the magnetic intensity is highest. Reconnaissance geology and magnetometer surveys were carried out and trenches on the west side of the lake were sampled. Between January and March 1976, ground magnetic coverage was completed over the lake surface and two vertical diamond-drill holes totalling 168 m were completed (B1 and B2 in Figure 29). Sections of magnetite mineralization were split and assayed for Cu, Ni, Ti, Cr and soluble Fe. This work indicated the presence of low-grade titaniferous magnetite mineralization.

Geology

The area is underlain by Precambrian rocks of the La Ronge Domain. Basic metavolcanics predominate, and these have been intruded by gabbroic, dioritic and granitic rocks (Padgham, 1960). The aeromagnetic anomaly corresponds to the Bassett Lake pluton, described by Padgham (1960) as a hornblende gabbro-hornblende diorite complex containing irregular masses of anorthosite. This study indicated that the pluton is in part a layered complex consisting of gabbro, olivine gabbro, magnetite-rich gabbro, peridotite and pyroxenite, along with norite, anorthosite and possibly hyperite (as defined by Moorhouse, 1959). The hornblendic varieties probably represent marginal facies of the pluton, where the rocks may have undergone a greater degree of metamorphism. The majority of the mineralogical changes observed, however, appear to be typical of incipient deuteric alteration rather than low-grade metamorphism.

The rocks tend to be massive and vary in grain size from 1 mm to several centimetres (in the pegmatoid phases). They contain abundant interstitial magnetite (as much as 30 percent but averaging 5 percent), disseminated to massive pyrrhotite-pyrite and local chalcopyrite.

Cumulate magmatic layering, although not obvious in outcrop, is clearly seen in drill core as alternating layers, 1 to 4 cm thick and rich in pyroxene, plagioclase and magnetite. Olivine also occurs as a primary cumulate, but magnetite occurs as an intercumulus phase, even in the magnetite-rich layers where it encloses euhedral pseudomorphs after pyroxene and/or plagioclase typical of banded complexes (Moorhouse, 1959). Small-scale magmatic layering is characterized by diffuse boundaries, similar to the "continuous mineral graded layering" of Goode (1976, p.392). On a larger scale, compositional and grain size changes between different phases (ie. gabbro, olivine gabbro and peridotite) are gradational and occur at scales ranging from 0.1 to 10 m. The felsic phases of the complex are typical of most banded complexes, occurring as irregular patches or sharply bounded veins.

In thin section the rocks show varying degrees of alteration and have diabasic, ophitic and layered textures. Most unaltered rocks contain twinned plagioclase, clino- and orthopyroxenes, magnetite and minor iron sulphides. Olivine is found occasionally. The more altered rocks are typically more magnetite rich and contain uralite pseudomorphs of pyroxene; saussuritized and sericitized plagioclase occurs, and olivine is in places altered to iddingsite.

Plagioclase, commonly subhedral, is usually andesine to labradorite in composition with some grains showing normal zoning. In a magnetite-rich peridotite (7511-271), the plagioclase grains are surrounded by rims of sericite, and in several thin sections blue hornblende needles cut the margins of the plagioclase grains. Anhedral clinopyroxene (typically diallage) and euhedral orthopyroxene are both present, with clinopyroxene commonly being more abundant. Fresh pyroxene is abundant in places, but uralitized pseudomorphs are more prevalent, especially in magnetite-rich varieties. Many of the uralitized pyroxenes are rimmed by tiny needles of blue hornblende, a feature generally attributed to strong deuteric alteration in gabbroic rocks (Moorhouse, 1959). Diallage remains evident in even the most altered of the rocks. Other alteration minerals from pyroxene include chlorite, talc and iron oxides.

Olivine has been observed (in thin sections 7511-252 and 7511-271) and possible talc-iron oxide pseudomorphs after olivine also occur (in thin section 7511-259). The olivine is subhedral and fresh to completely altered (to red-brown iddingsite). In one sample (section 271), the olivine is completely altered to iddingsite adjacent to a chloritized shear. Talc-iron oxide pseudomorphs, euhedral to

[1]Unofficial name.

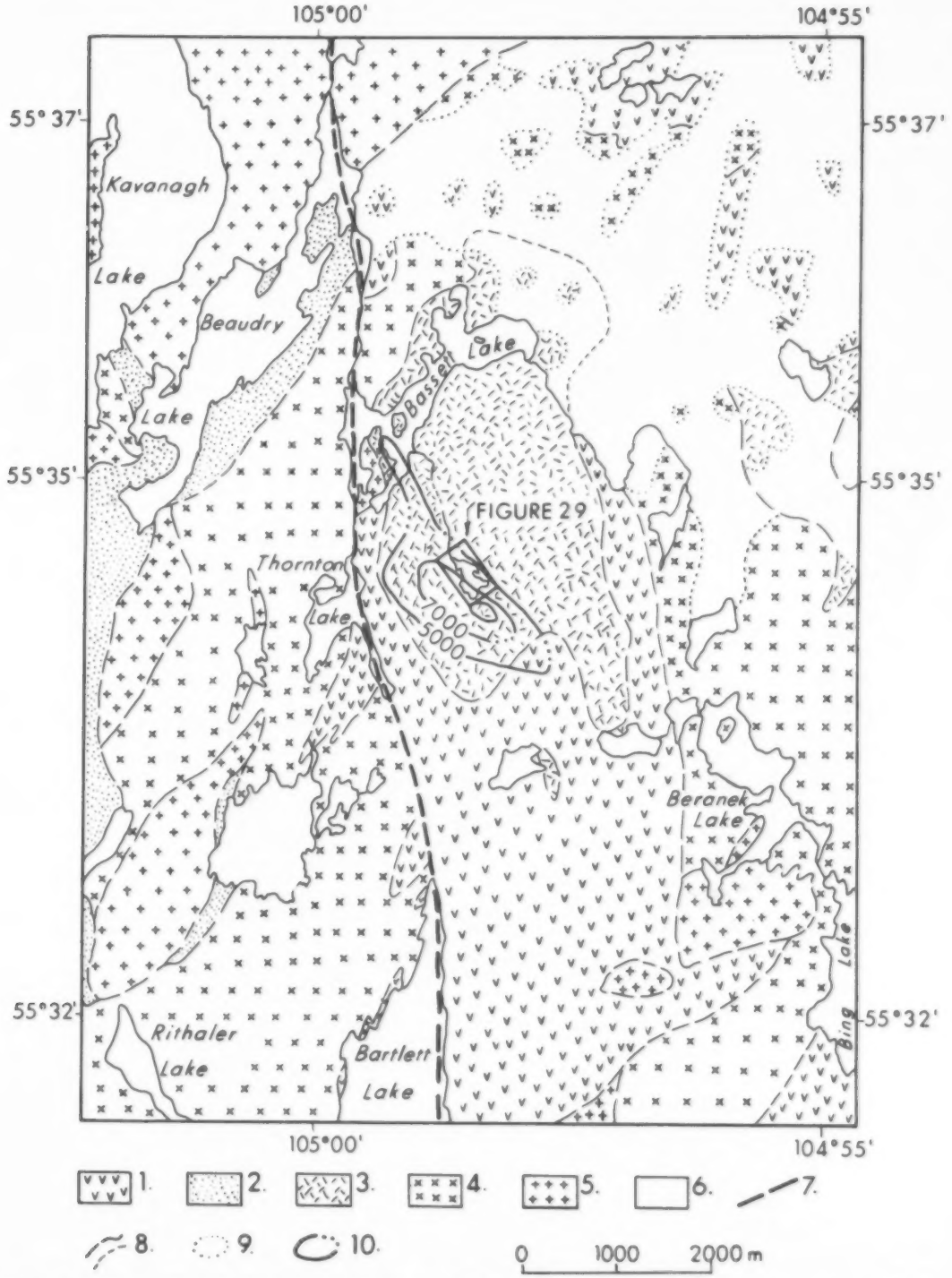


Figure 28. *Generalized geology of the Bassett Lake area, showing the location of the aeromagnetic anomaly. Geology adapted from Padgham (1960) and Morris (1960). 1, mafic to felsic metavolcanics and volcaniclastic metasediments; 2, biotitic metasedimentary gneisses; 3, basic and ultrabasic rocks, including gabbro, anorthosite, hornblendite, pyroxenite and hornblende diorite; 4, hornblende diorite to granodiorite; 5, granitic intrusives; 6, glacial deposits; 7, fault; 8, geological boundary (approximate, assumed); 9, limit of outcrop; 10, aeromagnetic contour (2000 gamma contour interval).*

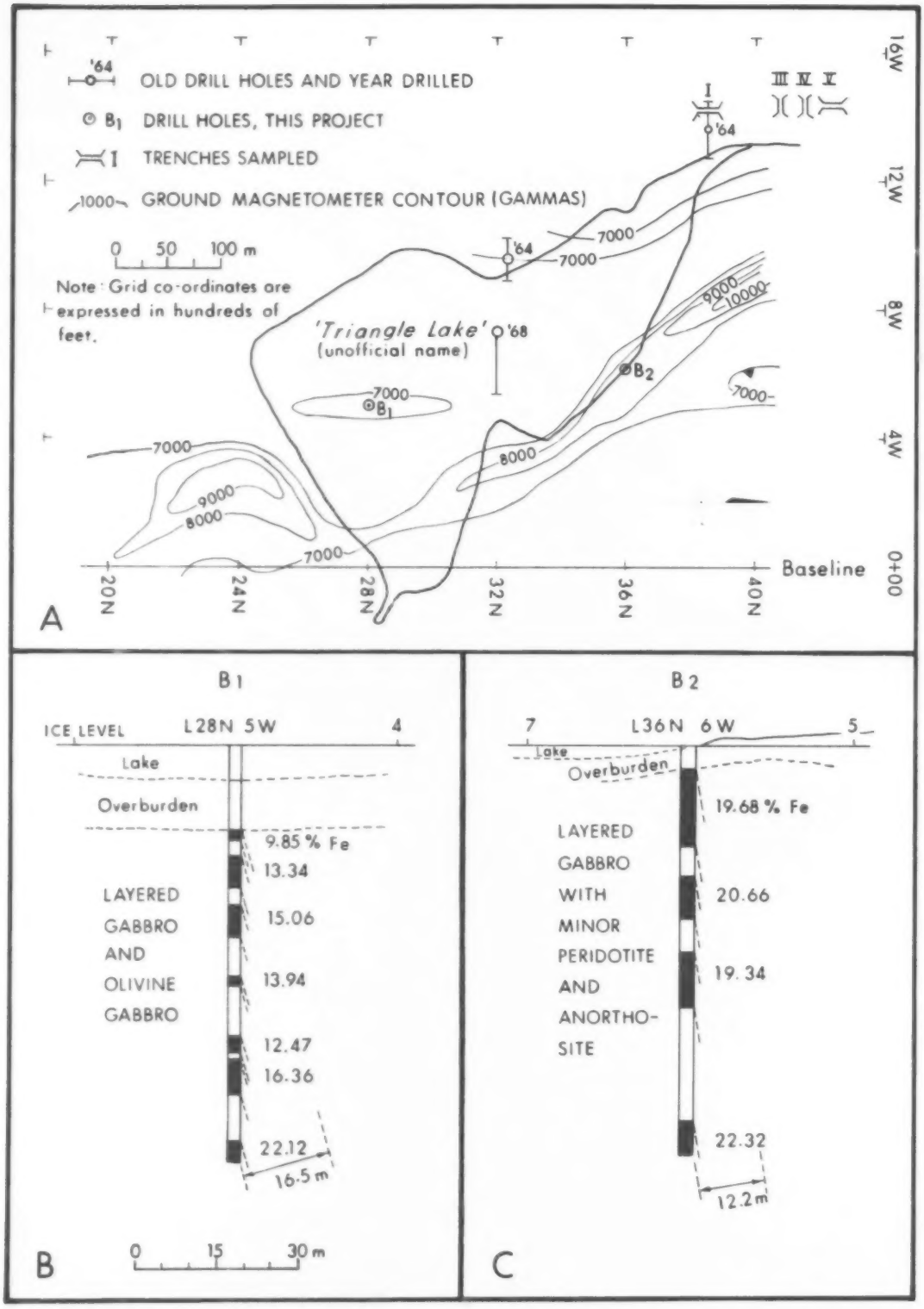


Figure 29. *Diamond-drill holes at Triangle Lake, Bassett Lake area. A, location of drill holes and trenches with respect to ground magnetic anomalies; B and C, rock types encountered and percent equivalent iron content of sampled core sections, drill holes B1 and B2.*

subhedral in shape, occur in a magnetite-rich layer. Pyroxene is also replaced by biotite (section 7511-258) and apatite occurs as a very minor accessory in most of the rocks.

Magnetite is a major constituent, making up 5 to 60 percent of the rocks. It is always interstitial or intercumulate to the other mineral grains, which tend to be aligned parallel to the layering. In the weakly altered rocks, silicate reaction rims separate the magnetite from the pyroxene grains.

The strongest alteration of the silicate minerals is invariably associated with the magnetite-rich portions of the rocks, suggesting that a close genetic relationship exists between the magnetite mineralization and deuteric alteration. Alternatively, the magnetite-rich parts may have provided channelways for the solutions that caused the alteration. In one polished ore section (7511-267), fine intergrowths of ilmenite accompany magnetite. Disseminated pyrrhotite and to a lesser extent pyrite are commonly associated with magnetite. Pyrrhotite constitutes up to 20 percent of any magnetite-rich layer. Pyrite commonly occurs as flattened euhedral grains concentrated in chloritized fractures. The magnetite with little doubt originated through magmatic differentiation in a layered basic complex.

Geochemistry

Nine composite rock chip samples[1], generally representing 3 m sections, were collected from four trenches along the west side of Triangle Lake[2]. These were assayed for Fe, Cu and Ni. Mineralized sections of the diamond-drill core were split and assayed for Ti, Cr, Cu and Ni; the iron content of magnetic separates was also determined. Four partial whole rock analyses (Ti, Al, Ca, Mg, Mn, Si, P, S, soluble Fe and moisture content) were made to determine the amounts of acceptable and undesirable elements (with respect to use as an iron ore) present in the rocks.

The analytical results from the composite trench samples are summarized in Table 20. The somewhat low soluble iron content in the trench samples includes iron from both oxides and sulphides.

The assay results from the diamond-drill core are summarized in Table 21. These results indicate that drillhole B2 is the more enriched in Fe, although B1 was still in mineralization when it was stopped. The

[1]Composite samples were made by taking chips at 0.3 m spacings along the trench and bagging them at 3 m intervals.

[2]Unofficial name.

Table 20. Summary of Analytical Results from Composite Trench Samples, Bassett Lake Area. All Values in Percent

Trench	Interval (m)	Fe	Cu	Ni
I	3	4.41	0.04	0.01
III	16.2	7.6	0.067	0.029
IV	3	6.21	0.05	0.01
V	3	16.6	0.04	0.02

mineralized sections average about 2 percent Ti, less than 0.01 percent in each of Cu, Ni and Cr, and contain about 30 percent magnetite. The magnetite averages about 16 percent Fe. The high titanium content (as much as 4.05 percent in a 1.3 m section) and the low grade combine to make this deposit undesirable as a source of iron.

The low grade of the occurrence is also indicated by the four partial whole rock analyses listed in Table 22. Titanium and sulphur are also unacceptably high. Although sulphur and silica could probably be substantially reduced during concentration, titanium is less likely to be reduced because it occurs as exsolution lamellae of ilmenite intimately associated with magnetite.

Geophysics

Readings for the ground magnetic survey were taken at 30 m intervals on land and at 15 m intervals over the lake. The land portion of the survey was completed in August 1975 and the lake was surveyed in January 1976. The results are presented at a scale of 1:4800 in Figure 29. Because of the high magnetite content, most of the rocks gave rather high background readings, ranging from 60 000 to 70 000 gammas. An anomalous zone, 30 to 120 m wide and outlined by the 70 000 gamma contour, extends north-northwest along the eastern side of the lake.

Economic Evaluation

The Bassett Lake iron occurrence is located within 12 km of Highway 102. The coarse grain size would probably make it amenable to coarse grinding and magnetic separation. Unfortunately the occurrence lacks the required grade and contains undesirable amounts of titanium and sulphur. Although the ground magnetic anomaly probably outlines the shape of the deposit, it would be unreliable for use in a tonnage determination without supporting geological information. A conservative estimate, of a deposit 900 m long with an average width of 60 m and mineable to a depth of 150 m, would indicate possible reserves of 27 million tonnes (30 million tons) with a grade of less than 20 percent Fe. More drilling would be required to determine the actual distribution of magnetite, and to evaluate the grade and quality in the central part of the magnetic

Table 21. Summary of Analytical Results from Diamond-Drill Core, Bassett Lake Area. All Values in Percent

Hole	Interval (m)	Core Length (m)	Soluble Fe	Ti	Cu	Ni	Cr
B1	14.9-17.4	2.5	8.53	0.94	0.013	0.010	0.003
	21.1-22.5	1.4	12.78	1.32	0.016	0.010	0.004
	24.1-26.5	2.4	13.34	1.53	0.013	0.011	0.005
	29.9-35.7	5.8	15.06	2.18	0.007	0.010	0.010
	43.3-44.8	1.5	13.94	1.92	0.006	0.009	0.008
	54.6-57.3	2.7	12.47	1.91	0.005	0.008	0.006
	58.8-65.2	6.4	14.22	1.75	0.005	0.008	0.007
	74.2-77.7	3.5	22.12	2.87	0.006	0.008	0.006
B2	4.3-18.3	14.0	19.68	3.05	0.007	0.009	0.010
	24.5-32.0	7.5	20.66	2.49	0.007	0.009	0.014
	38.9-48.6	9.7	16.34	2.67	0.009	0.011	0.012
	70.7-73.5	2.8	22.32	2.90	0.008	0.008	0.006

Table 22. Results for Partial Whole Rock Analyses on Samples of Mineralization from Drill Core, Bassett Lake Area. All Values in Percent

Drill Hole/ Sample Number	Sample Length (m)	Soluble Fe	Ti	Al	Ca	Mg	Mn	Si	P	S	Moisture Content
B1/180	1.00	11.9	1.38	7.0	6.7	3.9	0.13	17.8	0.028	0.74	0.06
B1/190	1.98	17.5	1.79	6.5	6.1	4.1	0.16	16.7	0.022	0.34	0.04
B2/200	1.65	18.6	2.23	4.8	4.7	6.0	0.22	14.7	0.018	0.42	0.04
B2/210	1.65	13.0	1.83	5.3	6.1	4.6	0.17	16.6	0.025	0.52	0.05

anomaly. The Bassett Lake occurrence is not rated as an economically viable deposit at present.

Clearwater River

This area, which lies 2.4 km east of the Clearwater River near Pickford Lake (Geological Survey of Canada, 1963c), was chosen for evaluation because of an aeromagnetic anomaly in excess of 7000 gammas and the presence of magnetite. The magnetite mineralization was reported by Abatis Exploration Limited of Calgary following reconnaissance prospecting of the area between 1968 and 1969 (Assessment File 74F01-0007). The anomaly was found to be caused by disseminated magnetite (up to 20 percent) in granitic to dioritic rocks.

Geology

The Clearwater anomaly lies within the Western Granulite Domain and is surrounded by high grade metamorphic rocks that consist of granitic, dioritic and possibly charnockitic gneisses, as well as minor metasedimentary gneisses. The anomaly occurs near the hinge zone of a steeply dipping and plunging, northeast-trending regional fold. Post-Hudsonian (?) north-northwest-trending transverse faults cross the area (see Scott, 1977 for additional information).

Much of the area is covered by glacial sands and gravels, and lies east of a large terminal moraine. The glacial deposits have been extensively reworked by wind and water. Post-glacial linear northwesterly trending sand dunes overlie other surficial features; some can be traced intermittently for more than 16 km, but they are generally 0.5 to 1 km long. Consistent northwest-converging dunes are elongate parabolic in form; the horns indicate a periglacial wind direction from the southeast. Ventifacts and sand-blasted polished surfaces on outcrops also suggest a southeasterly prevailing wind direction. Similar features have been reported by Tremblay (1961a), Johnson (1968), Wallis (1970) and Sibbald (1973, 1974) to the west, east and south of the Clearwater River area.

Meltwater channels are numerous and many are occupied by muskeg or small meandering streams. Several channels, especially that of the Clearwater River, are flanked by broad flat terraces at various heights above the present water levels.

Rock Descriptions

A 30 m band of **biotitic quartzofeldspathic gneisses** occurs on a small hill east of 'anomaly hill'. They are weakly to strongly limonite stained, coarse grained (2 to 3 mm) and have a well-developed gneissosity composed of alternating layers (0.1 to 5 cm thick) of

quartzofeldspathic and mafic (biotite ± hornblende ± pyroxene) minerals. Some garnet porphyroblasts occur, as well as widely disseminated pyrite and graphite (up to 2 percent). To the south these gneisses pass into migmatized, well-foliated, white- to light grey-weathering feldspar-quartz-biotite-hornblende-diopside gneiss. The biotitic quartzofeldspathic gneisses are probably metamorphosed sedimentary rocks.

Granitic, dioritic and charnockitic gneisses are the most abundant rocks in the area and appear to be gradational into one another. Pink-weathering coarse-grained rocks of granitic to granodioritic composition are abundant at 'anomaly hill'. They contain up to 10 percent hornblende, 20 percent magnetite and minor biotite. The dioritic rocks are coarse grained, light grey to grey-green and contain 10 to 20 percent mafic minerals. Rocks of possible charnockite composition are commonly light grey on weathered surfaces, dark grey on fresh surfaces and contain hypersthene. Both the diorites and charnockites contain as much as 10 percent disseminated magnetite. Magnetite content decreases to less than 1 percent away from 'anomaly hill' and the magnetic anomaly.

Structure

A strong penetrative foliation, related to an earlier episode of deformation, parallels the large regional folds. These later folds, with northeast-trending near-vertical axial surfaces and steep plunges, can be easily recognized on aerial photographs and on the aeromagnetic maps. No small-scale fold structures were observed in the area.

The Clearwater anomaly occurs near the hinge zone of a post-foliation fold that forms part of a large S-shaped fold on the southern limb of a much larger regional fold, 88 km in length.

Geophysics

Magnetic readings were taken at 60 to 90 m intervals at the north end of the large muskeg west of 'anomaly hill'. Background over the muskeg was generally recorded at about 60 000 gammas; the readings gradually increased to about 65 000 gammas near 'anomaly hill'. The highest readings occurred at the top of and on the western slope of the hill. Readings were taken at 15 m intervals on several closely spaced traverses across the hill.

The results of the detailed survey show a series of *en echelon* or parallel lineaments, perhaps representing isoclinal folds or lenticular masses of magnetite.

Table 23. Analytical Results from Rock Chip Samples, Clearwater River Anomaly. All Values in Percent

Sample Number	Soluble Fe	Mg	Mn	Ti
0128	3.41	3.56	0.11	0.59
0129	6.63	2.23	0.09	1.71
0130	9.74	11.6	0.15	0.47
Average	6.59	5.8	0.12	0.92

Economic Geology

Iron mineralization associated with the Clearwater anomaly consists of disseminated magnetite in granitic to dioritic rocks and minor disseminations of pyrite in quartzofeldspathic rocks, the latter being of little importance.

Magnetite occurs as anhedral to euhedral grains as well as aggregates up to 3 or 4 cm across. The aggregates, which occur in granitic to dioritic rocks, are limited to an oval-shaped area approximately 900 by 600 m. Many of the coarser aggregates are associated with small pods or zones of recrystallization; consequently, the magnetite may have been derived or concentrated through metamorphic processes. Visual estimates in the field indicate up to 20 percent magnetite in places; however, the average content is probably 10 percent or less over most of the area.

The results from three grab samples analyzed for soluble Fe, Mg, Mn and Ti are listed in Table 23. They average only 6.59 percent Fe, too low to give them any potential as a source of iron ore. In addition, titanium is above the desirable limit for iron ores.

Economic Evaluation

Field observations indicate that the Clearwater River anomaly is caused by disseminated magnetite contained in rocks of granitic to dioritic composition. Ground magnetics indicate linear, perhaps lens-shaped concentrations of magnetite; the structure is possibly complex. The occurrence is uneconomic at present because of its low grade and isolated location. If it could be mined in a similar fashion to porphyry coppers, it might be of economic interest in the future as it may contain in excess of 270 million tonnes (300 million tons) of low grade ore.

Olsen Showing

A vertically inclined pod of titaniferous hematite, measuring about 50 by 10 m and located on the east side of a small lake 8 km west of Upper Foster Lake, has been known since at least 1954. An initial report (Assessment File 74A12-NE-0007) indicated that it

was too small to be of economic interest. The showing has been repeatedly staked and examined over the years, but no further work has been reported.

The massive pod occurs in a pink to red, rotted, diopsidic pegmatite containing disseminations and veins of titaniferous hematite which decrease in abundance away from the pod. The pegmatite has a gradational contact with the surrounding meta-arkoses of the Wollaston Group (Ray, 1977).

The non-magnetic mineralization, blue-black in colour and coarse grained, is almost completely free of inclusions, except near the pegmatite. Polished section study revealed the presence of narrow oriented exsolution blades of ilmenite in the massive hematite host. Assays of the massive material returned 9.8 percent TiO_2 and 59.9 percent Fe (Assessment File 74A13-NE-0007).

Although disseminated mineralization was reported to extend along strike for several kilometres, no additional massive pods were discovered. Besides being too small and too remote geographically, the mineralization contains too much titanium to be an iron deposit and too little to be a titanium deposit. The extremely fine grained nature of the ilmenite exsolution blades would also make separation difficult.

Other Occurrences

Kelic Lake

The Kelic Lake aeromagnetic anomaly, located about 30 km northeast of the Clearwater anomaly, is greater than 5800 gammas (Geological Survey of Canada, 1964a) and, based on an interpretation of the aeromagnetics, is believed to lie along strike from the Clearwater anomaly.

The Kelic Lake anomaly lies in the Western Granulite Domain just south of the margin of the Athabasca Group. The surrounding area is completely covered with drift and muskeg. Ground magnetics define a lenticular, low magnitude anomaly that extends in a northeasterly direction for at least 1320 m and attains widths of up to 120 m. The anomaly, like the Clearwater anomaly which it resembles, is probably caused by disseminated magnetite contained in granitic to dioritic gneisses. No economic importance is attached to this anomaly because the mineralization appears to be disseminated and the magnetic anomaly is of low magnitude (maximum of only 66 920 gammas).

Popplewell Island

A small aeromagnetic anomaly in excess of 5500 gammas (Geological Survey of Canada, 1965a) is located over the western half of Popplewell Island, Frobisher Lake. Popplewell Island lies in a belt of partially migmatized supracrustals in the Mudjatik Domain (Tremblay, 1961b) consisting of quartz-plagioclase-biotite gneisses and minor hornblende gneisses. Most of the western part of the island is covered by bouldery till and muskeg, but a few small exposures of dark grey to black coarse-grained well-foliated quartz-feldspar-biotite gneiss and hornblende-biotite gneiss were observed.

The magnetic anomaly, roughly oval-shaped and measuring 300 by 240 m, is located midway between the north and south shores of the island (Figure 30) in an area of muskeg. The anomaly could be due to 1) sedimentary iron formation, 2) massive pyrrhotite mineralization, or 3) magnetite-bearing plutonic rocks.

The common association of sedimentary iron formation with biotitic and hornblendic rocks in the Mudjatik Domain, as well as the extension of the aeromagnetic trends from areas of known iron formation, lends support to the first interpretation. Basic plutonic rocks are also common, but massive sulphides are comparatively rare in the Mudjatik Domain.

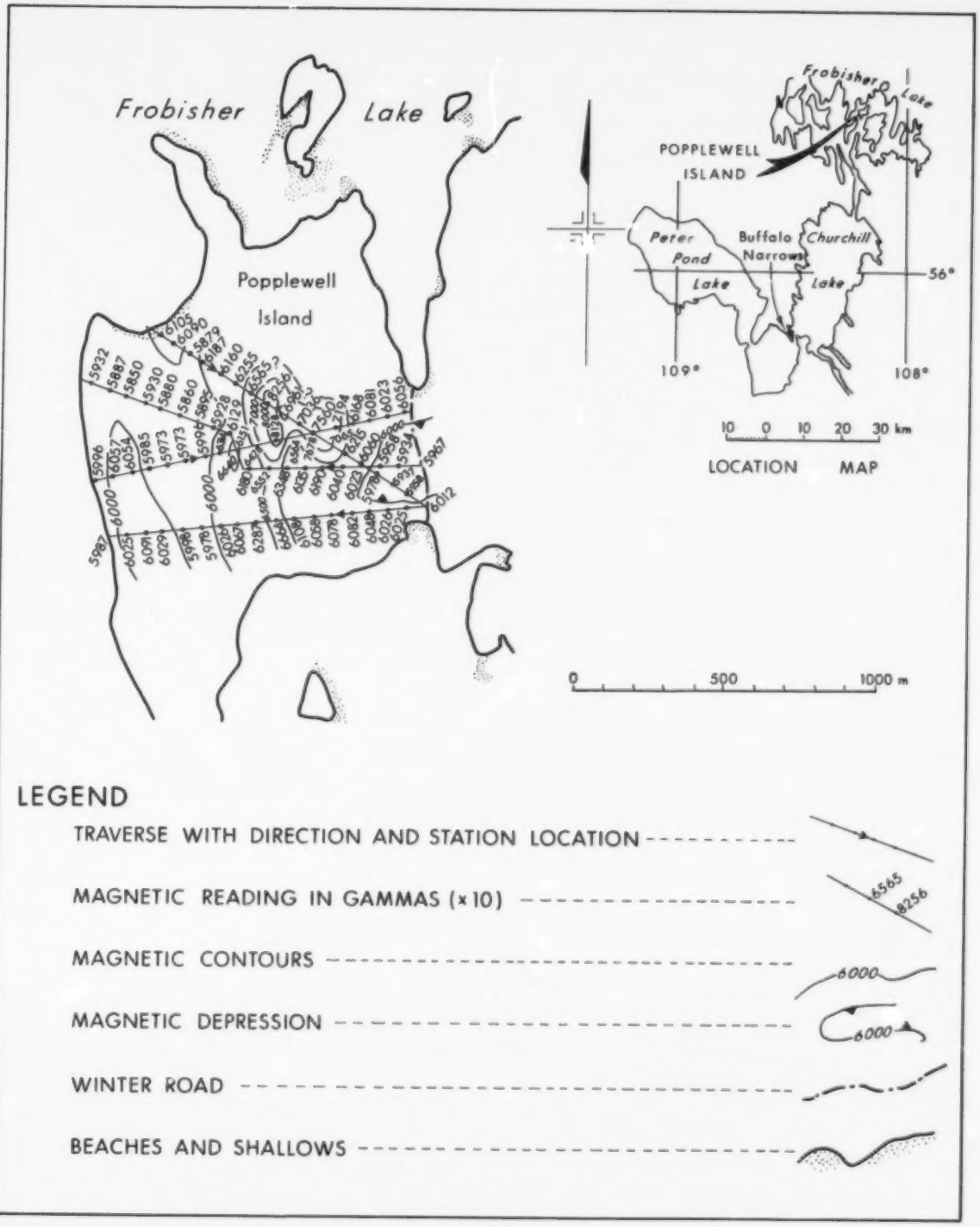


Figure 30. *Ground magnetic results, Popplewell Island. Compiled from field work by the author.*

Environment and Origin of the Iron Deposits

Metataconite Deposits

Most of the metataconite deposits are confined to the Mudjatik and Virgin River Domains, where intense deformation and metamorphism have destroyed most of the primary sedimentary and volcanic features. However, some indication of the depositional environments of the iron formations can be obtained from rock associations. Metataconite iron formation at Fish Hook Bay in the Athabasca Region was also examined.

Deposition of the supracrustals of the Virgin River, Mudjatik and Wollaston Domains probably occurred in a tectonically quiet, shallow marine to subaerial environment (Sibbald et al., 1977). Rock suites indicative of this type of environment are associated with most of the Virgin River-Mudjatik metataconites.

Arkoses, pelites, quartzites and conglomerates probably represent clastic wedges derived from granitoid basement highlands. Pelitic sediments are the most widespread. The extrusion of flood basalts (now mafic granulites), centred in the Mudjatik Domain, was accompanied by deposition of pyroclastics and volcaniclastic sediments, intrusion of basic and ultrabasic masses, and precipitation of iron formation (e.g. Dot Lake). Intermittent clastic sedimentation accompanied the volcanic episode. Precipitation of iron formation continued into the post-volcanic period and was commonly accompanied by deposition of ferruginous and iron-free quartzites (cherts ?). A later arkosic-pelitic sequence is associated with minor calcareous sediments, carbonates and iron formation. Similar arkosic sequences in northeastern Manitoba are believed to represent a continental blanket deposit (Sibbald et al., 1977).

Although iron formations occur at different stratigraphic levels, most have two features in common: 1) they are accompanied by and gradational to ferruginous and/or garnetiferous quartzites and iron-poor quartzites, and 2) they show a close spatial relation to mafic granulites (metavolcanics). Both the VH and Triana deposits are associated with pelitic sediments and amphibolites. There are three possible explanations for the origin of these iron formations: 1) they precipitated prior to the onset of volcanism and the amphibolite represents metamorphosed limy sediments or part of the basement complex; 2) they represent distal accumulations deposited contemporaneously with volcanism located elsewhere in the Mudjatik basin; or 3) they represent post-volcanic distal accumulations. The last two suggestions seem more likely.

Similar associations are found in the Messina Formation of the Limpopo mobile belt of southern Africa (Beukes, 1973), the Krivoy Rog area of southwestern U.S.S.R. (Alexandrov, 1973) and the Hammersley Group of Western Australia (Trendall, 1973). Deposition in all these examples began with an early period of clastic sedimentation followed by an episode of volcanic activity and completed by an episode of clastic and chemical sedimentation. Although iron formation can occur at different stratigraphic levels, most is associated with the waning or post-volcanic period.

It is still not known whether the iron and silica found in the banded cherty iron formations is derived from sedimentary, sedimentary-volcanic or volcanic exhalative sources. There does, however, seem to be a general acceptance that volcanism is the most likely source for most if not all of the iron and silica. This is especially true for Algoma- and Superior-type iron formations (Gross, 1965), and is supported by the close spatial relationship of most of the Virgin River-Mudjatik iron formations with rocks of presumed volcanic origin. These rock associations indicate an environment seemingly transitional between strictly continental shelf and eugeosynclinal; hence, the iron formations cannot be classified as either Algoma or Superior type.

The Fish Hook Bay iron formation in the Beaverlodge area is associated with shallow water, near-shore clastic and chemical sediments. The oldest rocks in the area consist of a thick sequence of granular, massive and brecciated quartzites containing lenses of conglomerate, pelite and dolomite. Channel scours and cross-beds indicate an agitated or high energy environment, but areas providing the restricted conditions favourable for deposition of mudstones and carbonates must have been present. Overlying the quartzite is a thick sequence of chemical precipitates including, in order of decreasing age: calcareous banded iron formation with intercalations and lenses of dolomite; dolomite and siliceous dolomite; and relatively pure banded iron formation. Soft sediment structures are present in the iron formations low in the succession, and many dolomite lenses show clastic structures such as cross-bedding. These chemical sediments are overlain by younger quartzites and pelite followed by more dolomite and ferruginous dolomite.

The sedimentary sequence in the Beaverlodge area is somewhat similar to carbonate sedimentary cycles in the Transvaal Supergroup of South Africa, where banded iron formation is though "to be an end member in a series of chemical and sedimentary cycles ... caused [by] a partial restriction between the iron-formation environment and the open ocean" (Button, 1976, p.193).

The Fish Hook Bay assemblage is part of the Murmac Bay Formation (Tremblay, 1972) which also contains pelitic metasediments and amphibolites of sedimentary and volcanic origin. These rocks occur farther west and north from Fish Hook Bay and undoubtedly represent sediments deposited in a deepening basin. Many characteristics of Superior-type iron formations are present; that is, the rocks "are associated with continental shelf and miogeosynclinal sediments composed of well-sorted detrital and chemical constituents derived from a maturely weathered land mass .... Coarser clastic sediments deposited near shore have cross-bedding, ripple-marks, and other primary features typical of shallow-water environment where wave and current action are prominent" (Gross, 1965, p.119-120). Volcanic rocks commonly occur in the succession and in many cases are contemporaneous with deposition of the iron formation. Rocks believed to be volcanic in origin are present in the Murmac Bay Formation. In the Fish Hook Bay area, the iron formations are rather restricted lenticular deposits, in contrast to the "long continuous formations extending for hundreds of miles" (*ibid.*, p.120) which are more typical of Superior-type iron formations. Perhaps the iron formation presently exposed on the north shore of Lake Athabasca is only a remnant of a much larger succession of platform sedimentary rocks.

On the basis of these observations, it seems that the Fish Hook Bay iron formation was probably precipitated under conditions similar to those existing during the deposition of the Superior-type iron formations. Iron and silica may be in part derived from a contemporaneous offshore volcanic belt or from a maturely weathered landmass of low relief.

The stratigraphy of the Spence Lake iron formation is similar to that of Fish Hook Bay, but instead of the greater thickness of carbonates, calcareous muds and silts preceded deposition of the silicate and oxide facies iron formation. The arguments applied to Fish Hook Bay also apply to Spence Lake. Volcanic rocks are present in the lower portion of the sequence. Unlike Fish Hook Bay, the Spence Lake occurrence has been traced for many kilometres by various geophysical methods. Most features thus suggest a Superior-type iron formation.

Sulphide Deposits

By far the greatest concentration of sulphide occurences is in the La Ronge Domain, where three areas, Nistoassini Lakes, Kirk Lake and Forbes Lake, were examined. A few narrow discontinuous zones of sulphide mineralization occur in the Rottenstone Domain, but only one of these, the Gossan Lake area, was examined. This discussion is concerned with bedded sulphide and barren massive sulphide deposits since they have the best potential as sources of iron ore.

The bedded and massive sulphide deposits occur in close association and in many cases grade into one another. The bedded deposits are characterized by layers of pyrite, pyrite-pyrrhotite, or less commonly pyrrhotite, generally less than 1 cm thick, interbedded with carbonaceous siliceous argillite or shale and/or carbonaceous felsic tuff. Layering is disrupted where sulphides have been remobilized into fractures, boudin necks and other voids produced during deformation. Penecontemporaneous slump structures are also common. The sulphide content is generally 10 to 40 percent, but in places may constitute as much as 80 percent of the rock, forming a massive sulphide deposit.

Massive deposits are usually composed of pyrrhotite with subordinate pyrite. Much of the massive pyrrhotite is brecciated, suggesting several possible modes of origin: 1) replacement, 2) intrusion, 3) slumpage, and 4) brecciation and recementation.

The close spatial relationship between the bedded and massive types suggests a genetic link. Both types occur in both the volcanic and sedimentary zones. Sulphides in the volcanic zone are almost everywhere associated with felsic volcanics. These areas, which include Nistoassini Lakes (Harper, 1974, 1976; Coombe, 1975), Kirk and Hump Lakes (Harper, 1974; Coombe, 1976), Jojay Lake (Coombe, 1975), Forbes Lake (Harper, 1975b, 1976) and Sulphide Lake (Coombe, 1975, 1976), are probably volcanic centres and the sulphides possibly represent proximal exhalites. In the sedimentary zone, sulphides are commonly associated with carbonaceous or graphitic shales or pelites and/or calc-silicate rocks. However, some of the sulphide occurrences in this zone are actually associated with interlayered volcanic rocks (e.g. Forbes Lake). The sulphides in the sedimentary zone are undoubtedly related to exhalative activity but probably represent deposits formed in a distal environment.

The bedded sulphides represent sulphide facies iron formation, the iron (and silica) being probably derived from volcanic exhalations (James, 1954; Gross, 1965; Ridler, 1973). Although the massive deposits may represent concentrated accumulations of iron sulphides or strongly recrystallized bedded deposits, the ultimate source of the iron is still probably volcanogenic.

The almost ubiquitous association of carbon with both types of deposits implies that reducing conditions were prevalent throughout most of the

depositional basin. The origin of this carbon, however, is unknown. The nearly complete lack of iron oxide facies iron formation and the absence of iron carbonate and iron silicate facies iron formations suggest that reducing conditions were widespread throughout the basin.

The presence of volcanic rocks and the abundance of sulphides suggest that the bedded and massive sulphide deposits of the La Ronge Domain are the result of volcanogenic exhalative activity occurring in both proximal and distal environments. The iron formations are similar to the Algoma type as defined by Gross (1965).

The origin of the iron sulphide occurrences in the Rottenstone Domain is more problematical because high grade metamorphism, deformation and migmatization have destroyed almost all recognizeable primary structures. Only gross lithologic layering is preserved. Sulphide mineralization observed at Gossan Lake (Harper, 1975b) is commonly associated with carbonaceous calcareous host rocks which resemble the distal exhalites of the La Ronge Domain.

Magmatic Deposits

Both the magnetite-bearing gabbroic rocks of the Bassett Lake gabbroic complex and the titaniferous hematite mineralization in pegmatite at the Olsen showing are clearly of magmatic origin. The Clearwater River occurrence is included tentatively in the magmatic group.

The Bassett Lake gabbroic complex, composed of gabbro, norite and anorthosite with minor peridotite, pyroxenite and diorite, intruded metavolcanic rocks of the La Ronge Domain. Primary layering, cumulate textures and the effects of deuteric alteration have been preserved, since the complex has undergone only minimal metamorphism. Magnetite, usually in either interstitial or intercumulate form, is a primary mineral phase in the complex, ranging in abundance from 5 to 60 percent.

The Olsen showing consists of a pod of massive ilmeno-hematite in a pink diopside-bearing pegmatoid host. The pegmatite contains abundant disseminated ilmeno-hematite that decreases in abundance with distance from the massive pod, as does the grain size of the pegmatite. The pegmatite grades into the enclosing country rocks (calcareous meta-arkoses of the Wollaston Group), a feature that characterizes most oxide-rich pegmatites (Puffer, 1975) Iron-titanium oxide-bearing pegmatites are believed to result from iron-rich vapours developed in response to metamorphism in deep-seated environments at temperatures of 600 to 700°C and pressures up to 10 kbars (*ibid.*).

The Clearwater occurrence consists of disseminated magnetite in granitic to dioritic rocks of supposed igneous origin in the Western Granulite Domain. However, as the Western Granulite Domain has undergone granulite facies metamorphism, the host rocks could be highly metamorphosed sediments or volcanics, and the magnetite may have been derived from metamorphic reactions. A plutonic association is favoured.

Residual Deposits

The residual deposits, including bog iron ores and limonite-cemented tills, occur in association with the iron sulphides. They have been especially noted in the La Ronge Domain (Johnston, 1971, 1972, 1973).

Tills commonly occur on the leeward or down-ice side of slopes, generally about a metre below the crest of the adjacent Precambrian outcrop. Johnston (1971) suggested that they were cemented during an interglacial period by iron leached from the underlying sulphide-bearing rocks, and were subsequently reworked and incorporated in younger tills. Limonite has apparently replaced the clay portion of the till matrix as well as the organic materials, and in addition has coated clasts and cobbles in the till. Many of the clasts are highly altered.

Bog iron ores are also forming presently in some swampy areas. They are composed of limonite, goethite and possibly manganese oxides, typically occur as crusty, nodular and botryoidal growths, and are friable. Organic material is replaced by goethite, thus preserving the delicate structure of moss and other plants. Pools of water associated with these deposits tend to be shallow, stagnant to slowly flowing, taste bitter and have a sulphurous smell.

Both types of residual deposits are formed by similar processes, in which iron is leached from sulphide-bearing strata, transported by ground or surface waters and then precipitated at or near the surface, replacing till matrix and organic matter or forming crusty or nodular material.

Economic Evaluation and Conclusions

The purpose of this program was to evaluate the economic potential of various iron deposits in northern Saskatchewan. To be economically viable, a deposit has to be capable of supplying 100 million tonnes grading at least 30 percent Fe, mineable by open pit methods, amenable to rather simple concentrating processes and accessible by existing transportation routes. A magnetite-bearing deposit with a relatively coarse grain size would best suit these reqirements, but other types (sulphides and hematite) were also investigated.

The Triana and VH deposits are the largest metataconite-type deposits in northern Saskatchewan and both have reasonable grades. However, both are geographically remote, and while Triana lacks the required size, the VH is still undergoing assessment. The Fish Hook Bay deposits on the north shore of Lake Athabasca are too far from smelting facilities and also lack the required size and grade. The Dot Lake iron formation and the other metataconite deposits of the Mudjatik Domain are much too small to be of interest.

The barren massive and associated bedded sulphide deposits (e.g. Nistoassini Lakes, Forbes Lake and perhaps Kirk Lake) could provide ample tonnage from open pit operations and all are within 20 km of existing roads. The major problem would be disposal of the large quantity of sulphur produced.

The Bassett Lake occurrence, the only sizeable magmatic deposit, lies within 16 km of existing roads, but it too fails to meet size and grade requirements. The ore also contains titanium, which makes it undesirable for smelting. The Olsen showing is too small, contains too much titanium and is quite inaccessible.

Residual deposits, although of acceptable grade, are too small to be of interest. However, they might become viable if mined in conjunction with nearby iron sulphides.

Although iron is an abundant metallic element in northern Saskatchewan, no economically feasible deposit of the metal appears to be indicated at the present time.

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Plates

Plate 1. *Fold interference patterns of banded quartz-magnetite iron formation. Dot Lake; pencil is 16.5 cm long*

Plate 2. *Cross-bedded channel scour in quartzite, Fish Hook Bay; divisions on pencil are 2.54 cm*

Plate 3. *Abrupt contact between quartzite (white and poorly treed) and lower iron formation (heavily wooded) exposed along east shore of Shirley Peninsula, Fish Hook Bay*

Plate 4. *Banded quartz-hematite iron formation of the lower iron formation unit with some thin white dolomitic interlayers (upper left), east shore of Shirley Peninsula, Fish Hook Bay; pencil is 9.5 cm long*

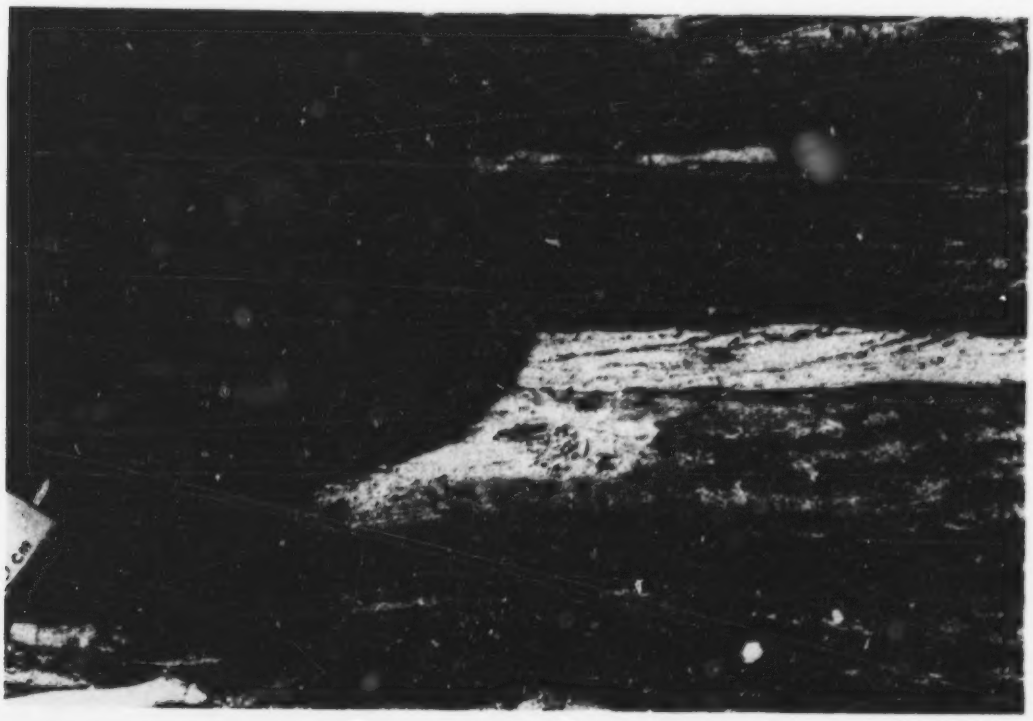


Plate 5. *Crossbedded dolomite interlayer within lower iron formation, east shore of Shirley Peninsula, Fish Hook Bay; paper sample bag is 10 cm wide*

Plate 6. *Irregular masses of specularite (black) on fracture surfaces of dolomite (lighter greys), west shore of Shirley Peninsula, Fish Hook Bay*

Plate 7. *Rhyolite flows encased in felsic tuffs near top of felsic volcanic sequence, about 1 km north of Kenwood River, Nistoassini Lakes area; pen is about 15 cm long*

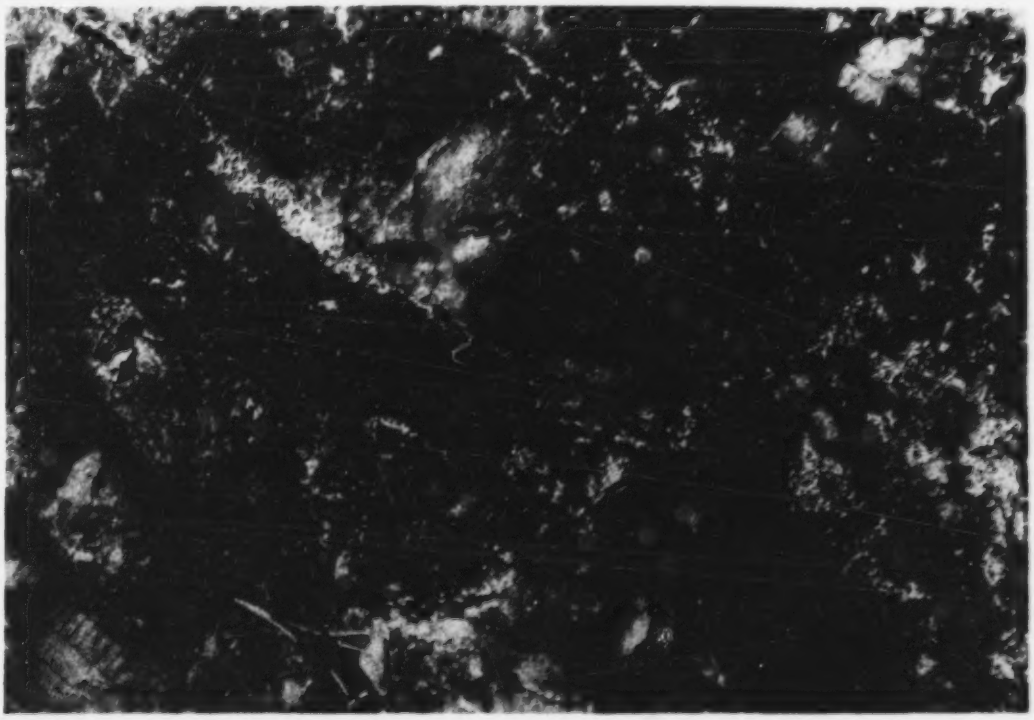


Plate 8. *Pyritic explosion breccia at top of felsic volcanics, about 1 km north of Kenwood River and just east of small narrow lake, Nistoassini Lakes area; note pyrite grains and stringers lining rhyolite fragments; darker areas between fragments contain very fine pyrite in a carbonaceous groundmass of comminuted rhyolite; portion of scale shown is 5.5 cm long*

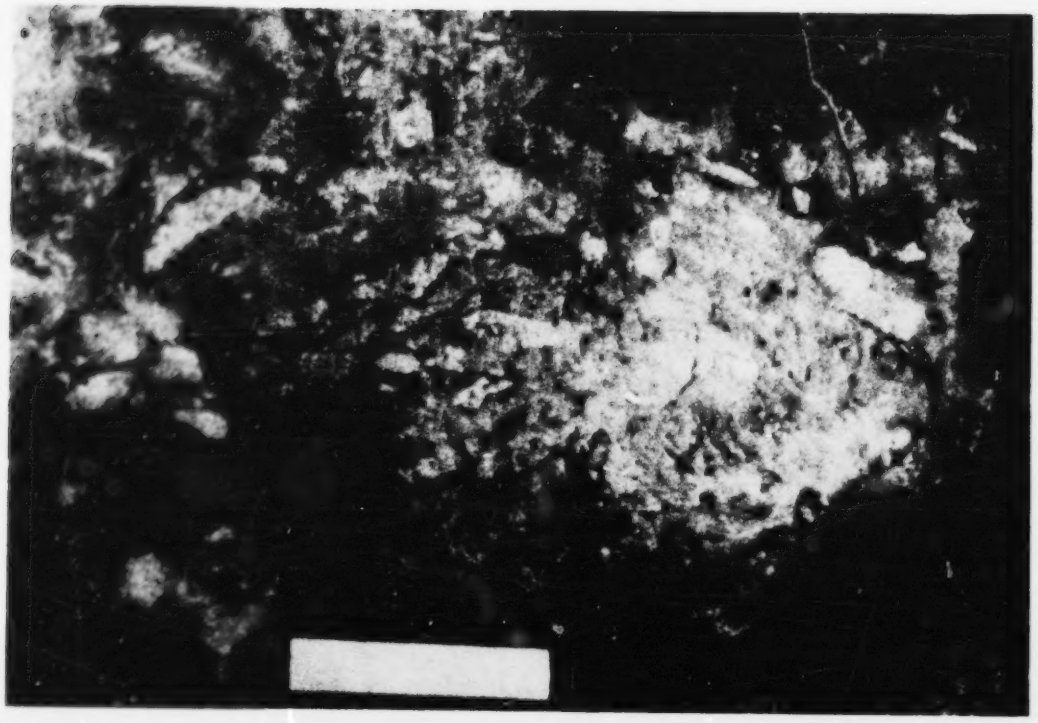


Plate 9. *Strongly iron stained rhyolite agglomerate at top of felsic volcanic sequence, about 10 m in from southwest corner of northern bay of Lower Nistoassini Lake; scale is 15.2 cm long*

Plate 10. *Finely laminated argillite, on east side of small lake 1.5 km west of north end of Greenhill Lake, Nistoassini Lakes area; pencil (9.5 cm long) points to slight upwelling of bedding and subsequent truncation of the beds by a younger cycle*

Plate 11. *Felsic volcanic breccia of the Pillow Lake dome, near east shore of Lower Nistoassini Lake on trend of Churchill Minerals showing; note extreme elongation of these fragments and dark colour of the matrix material; scale is 15.2 cm long*

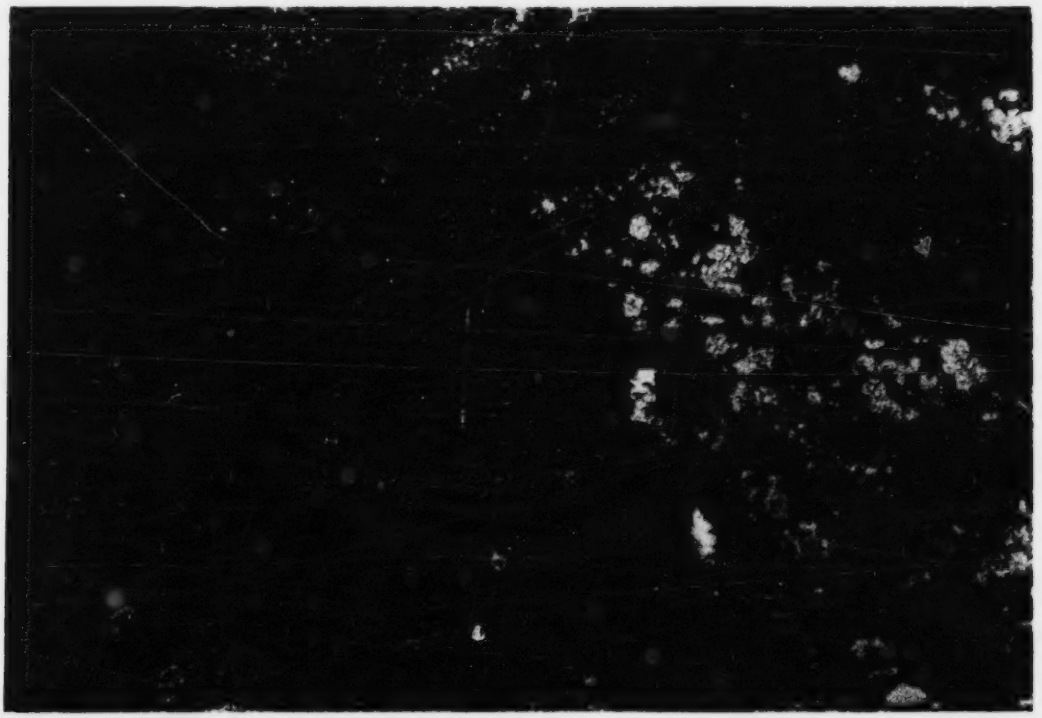


Plate 12. *Basaltic pillow lavas exposed on a small island in Lower Nistoassini Lake; pencil (9.5 cm long) points south and indicates the top*

Plate 13. *Angular granitic clast within a pebbly arkosic matrix in the conglomeratic unit of the western sediments, about 1 km northeast of the second rapids on Kenwood River, Nistoassini Lakes area; exposed portion of the pencil is 10 cm long*

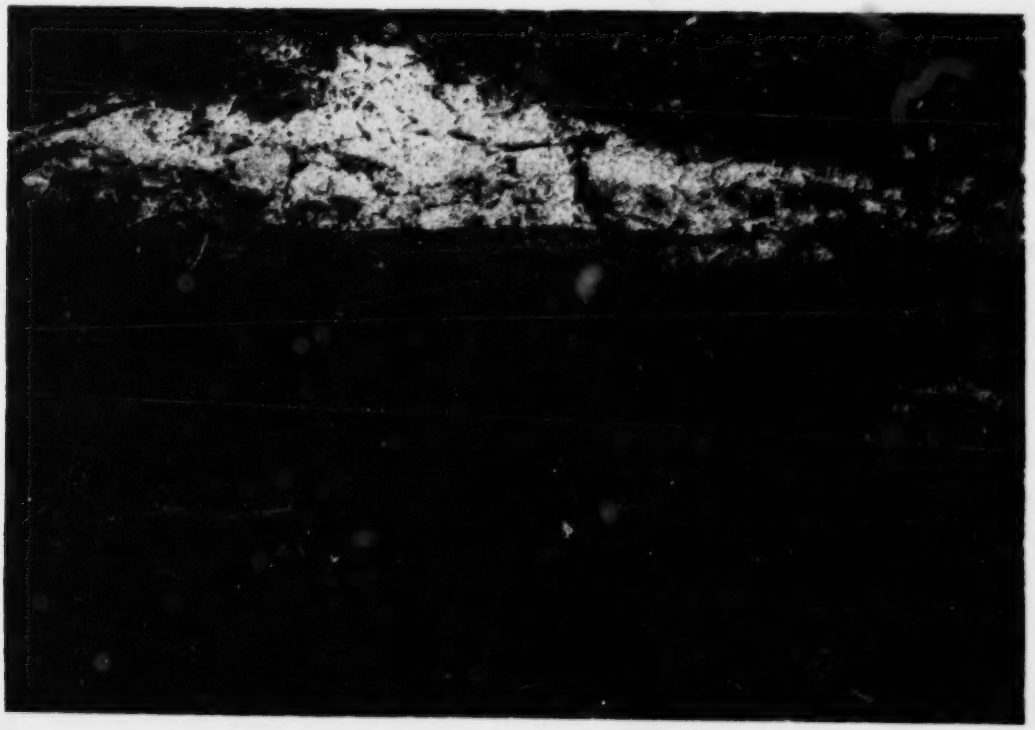


Plate 14. *Channel scour-and-fill structure in greywacke unit of the Western Sediments, about 1 km southwest of small lake at northwestern extremity of Nistoassini Lakes map area; pencil is 9.5 cm long and points southeast*

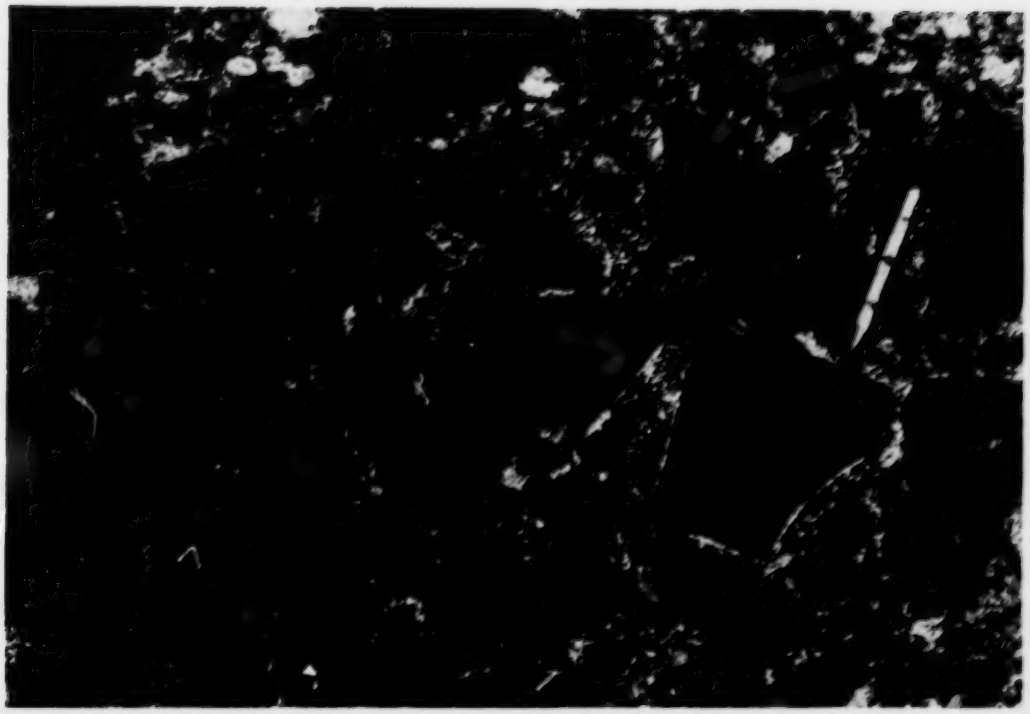


Plate 15. *Intrusive breccia along southern contact of Greenhill Lake gabbro body, about 1 km west from midpoint of west shore of Greenhill Lake, Nistoassini Lakes area; many fragments have bleached rims (pencil point); pencil is 9.5 cm long*

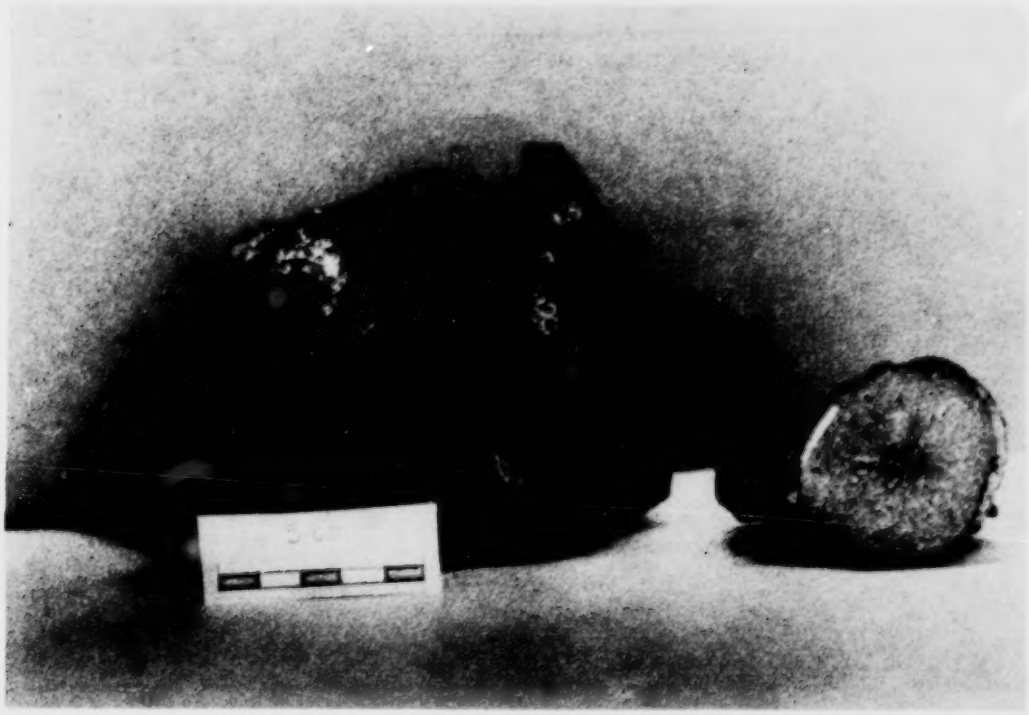


Plate 16. *Pyrite-pyrrhotite nodules showing concentric and radial patterns, Nistoassini Lakes area*

Plate 17. *Typical example of bedded sulphide-type mineralization showing penecontemporaneous slump folds, Nistoassini Lakes area*

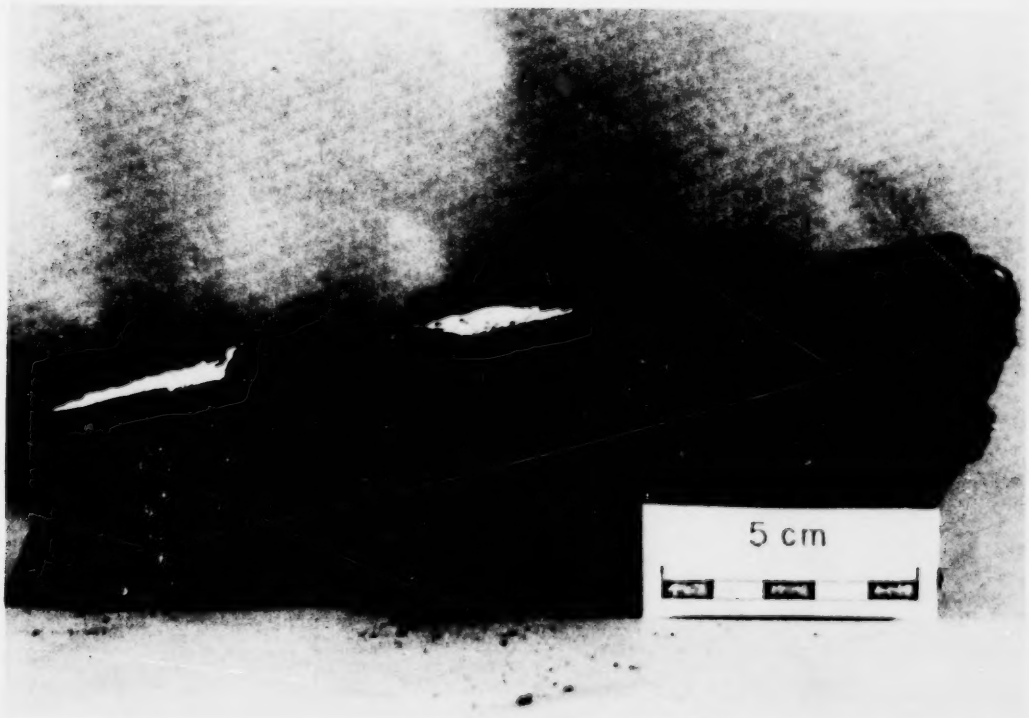


Plate 18. *Massive sulphide mineralization showing well-defined sedimentary structures, Nistoassini Lakes area*

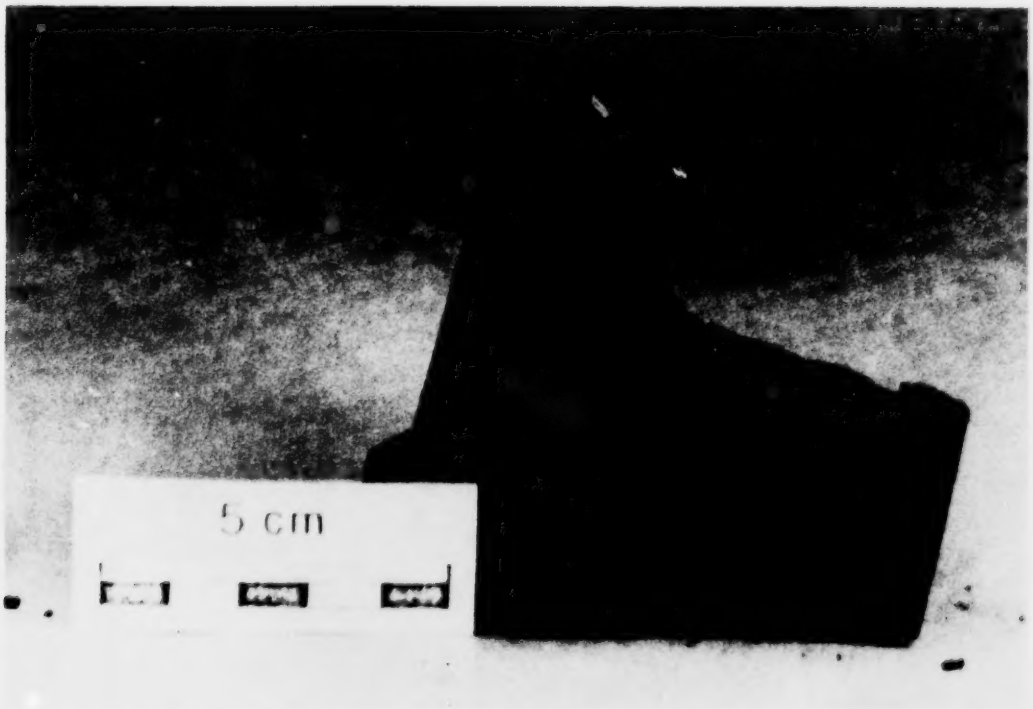


Plate 19. *Brecciated-type massive sulphide mineralization, Nistoassini Lakes area*

Plate 20. *Nodular and granular bog iron ore exposed on dry lake bottom at southwest end of Central Lake (unofficial lake name), Forbes Lake area; clip board is about 35.5 cm long*

Figure 13. *Detailed geology in the immediate vicinity of Fish Hook Bay. Locations of stratigraphic sections A-A' to D-D' (see Figure 14) and rock samples are indicated. Compiled from assessment work submitted to Saskatchewan Energy and Mines and from field work by the author (Harper, 1976). Inset: part of section C-C' (mapped in detail) on the east side of Shirley Peninsula.*

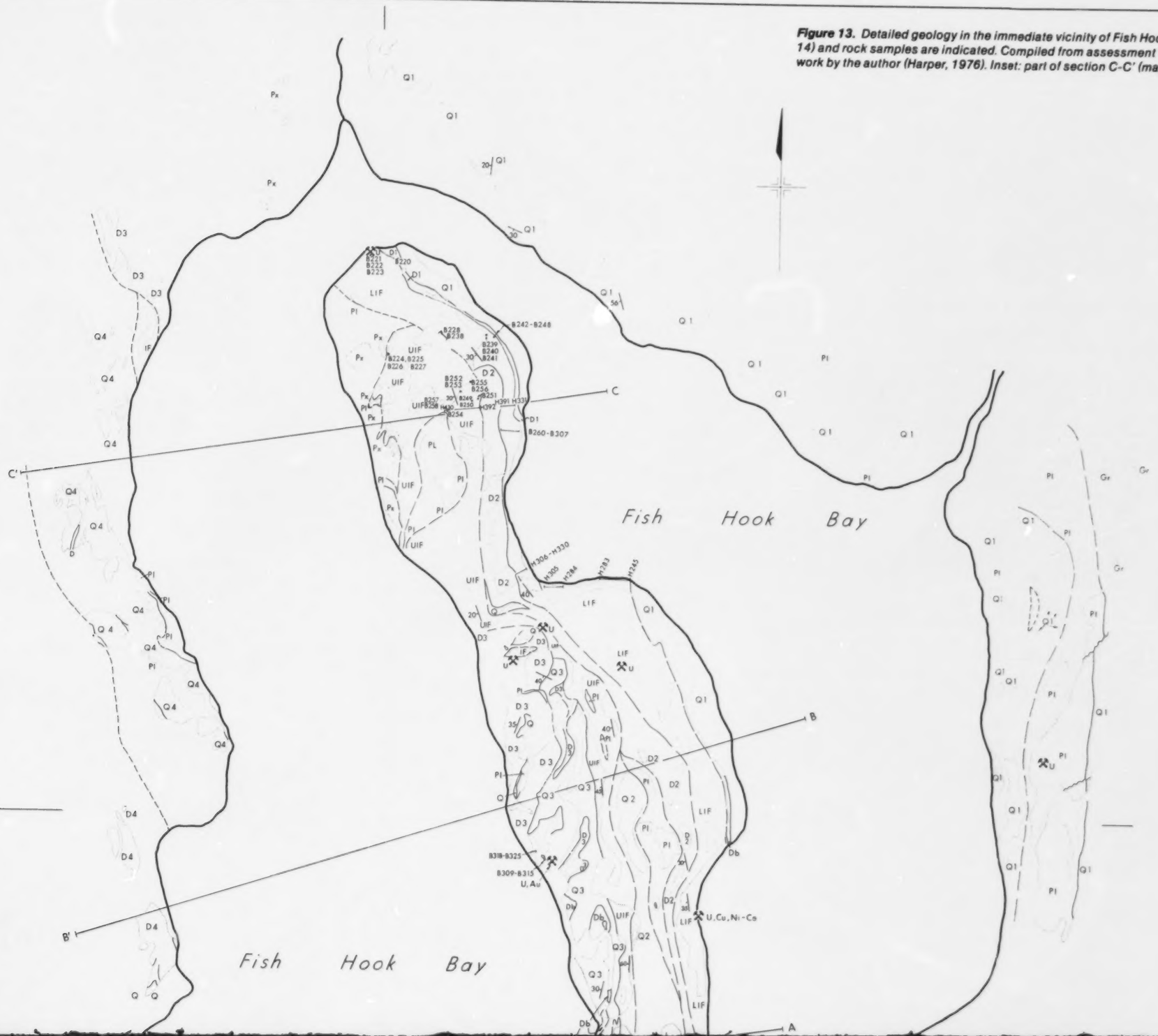
LEGEND

- **Db** Diabase, dark green to black, fine grained
- **Px** Pyroxenite, dark green, coarse grained and massive
- **D4** Dolomite (as D1), ferruginous dolomite with minor quartzite
- **Q4** Quartzite (as Q1), minor metapelite
- **D3** Dolomite (as D1), ferruginous dolomite, minor quartzite, metapelite and iron formation
- **Q3** Quartzite (as Q1), minor dolomite
- **UIF** Upper Iron Formation, cherty hematite (± magnetite) iron formation, including some silicate facies iron formation and metapelites
- **Q2** Quartzite (as Q1)
- **Pl** Metapelitic rocks, biotitic, fine grained, dark brown to black, sometimes containing amphibole
- **D2** Dolomite (as D1), with interbedded iron formation, diopsidic dolomite and minor quartzite
- **LIF** Lower Iron Formation, cherty hematite (earthy to specular) and dolomitic iron formation with dolomite interbeds
- **D1** Dolomite, massive to well bedded, chocolate brown weathered, crystalline, often having clastic textures, minor diopsidic sections and iron formation
- **Q1** Quartzite, white, buff and green, granular, massive to well bedded, with minor conglomerate and metapelite
- **Gr** Granite

SYMBOLS

- Area of outcrop
- Geological boundary (defined, assumed)
- Bedding (inclined)
- A—A' Line of stratigraphic section
- H283—H245 Sampled section
- •B309-B315 Samples listed in Table 10
- ⚒ Mineral occurrence
- U Uranium
- Cu Copper
- Ni-Co Nickel-cobalt
- Au Gold

Figure 13. *Detailed geology in the immediate vicinity of Fish Hook Bay. Locations of stratigraphic sections A-A' to D-D' (see Figure 14) and rock samples are indicated. Compiled from assessment work submitted to Saskatchewan Energy and Mines and from field work by the author (Harper, 1976). Inset: part of section C-C' (mapped in detail) on the east side of Shirley Peninsula.*



LEGEND

Db	Diabase, dark green to black, fine grained
Px	Pyroxenite, dark green, coarse grained and massive
D4	Dolomite (as D1), ferruginous dolomite with minor quartzite
Q4	Quartzite (as Q1), minor metapelite
D3	Dolomite (as D1), ferruginous dolomite, minor quartzite, metapelite and iron formation
Q3	Quartzite (as Q1), minor dolomite
UIF	Upper Iron Formation, cherty hematite (± magnetite) iron formation, including some silicate facies iron formation and metapelites
Q2	Quartzite (as Q1)
Pl	Metapelitic rocks, biotitic, fine grained, dark brown to black, sometimes containing amphibole
D2	Dolomite (as D1), with interbedded iron formation, diopsidic dolomite and minor quartzite
LIF	Lower Iron Formation, cherty hematite (earthy to specular) and dolomitic iron formation with dolomite interbeds
D1	Dolomite, massive to well bedded, chocolate brown weathered, crystalline, often having clastic textures, minor diopsidic sections and iron formation
Q1	Quartzite, white, buff and green, granular, massive to well bedded, with minor conglomerate and metapelite
Gr	Granite

SYMBOLS

- Area of outcrop
- Geological boundary (defined, assumed)
- Bedding (inclined)
- A—A' Line of stratigraphic section
- H283—H245 Sampled section
- •B309-B315 Samples listed in Table 10
- Mineral occurrence
- U Uranium
- Cu Copper
- Ni-Co Nickel-cobalt
- Au Gold

Fish Hook Bay

Fish Hook Bay

LEGEND

- **Db** Diabase, dark green to black, fine grained
- **Px** Pyroxenite, dark green, coarse grained and massive
- **D4** Dolomite (as D1), ferruginous dolomite with minor quartzite
- **Q4** Quartzite (as Q1), minor metapelite
- **D3** Dolomite (as D1), ferruginous dolomite, minor quartzite, metapelite and iron formation
- **Q3** Quartzite (as Q1), minor dolomite
- **UIF** Upper Iron Formation, cherty hematite (± magnetite) iron formation, including some silicate facies iron formation and metapelites
- **Q2** Quartzite (as Q1)
- **Pl** Metapelitic rocks, biotitic, fine grained, dark brown to black, sometimes containing amphibole
- **D2** Dolomite (as D1), with interbedded iron formation, diopsidic dolomite and minor quartzite
- **LIF** Lower Iron Formation, cherty hematite (earthy to specular) and dolomitic iron formation with dolomite interbeds
- **D1** Dolomite, massive to well bedded, chocolate brown weathered, crystalline, often having clastic textures, minor diopsidic sections and iron formation
- **Q1** Quartzite, white, buff and green, granular, massive to well bedded, with minor conglomerate and metapelite
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SYMBOLS

- Area of outcrop
- Geological boundary (defined, assumed)
- Bedding (inclined)
- A–A' Line of stratigraphic section
- H283–H245 Sampled section
- •B309–B315 Samples listed in Table 10
- Mineral occurrence
- U Uranium
- Cu Copper
- Ni-Co Nickel-cobalt
- Au Gold

59°27'30"

108°24'

108°40'

59°20'

LOCATION MAP

10 0 10 km

URANIUM CITY

Beaverlodge Lake

AREA OF DETAIL

LAKE ATHABASCA

0 50 100 150 200 250 300 m

PART OF SECTION C–C'

250 m

230 m

210 m

H430 H392 H391 H331

FISH HOOK BAY

0 10 20 30 40

UIF UPPER IRON FORMATION

DIOPSIDIC DOLOMITE

DOLOMITE

BANDED IRON FORMATION

LIF LOWER IRON FORMATION

QUARTZITE

Fish Hook Bay

Fish Hook Bay

59°27'30"

108°24'

0 50 100 150 200 250 300 m

LEGEND

- **Db** Diabase, dark green to black, fine grained
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- **D4** Dolomite (as D1), ferruginous dolomite with minor quartzite
- **Q4** Quartzite (as Q1), minor metapelite
- **D3** Dolomite (as D1), ferruginous dolomite, minor quartzite, metapelite and iron formation
- **Q3** Quartzite (as Q1), minor dolomite
- **UIF** Upper Iron Formation, cherty hematite (± magnetite) iron formation, including some silicate facies iron formation and metapelites
- **Q2** Quartzite (as Q1)
- **Pl** Metapelitic rocks, biotitic, fine grained, dark brown to black, sometimes containing amphibole
- **D2** Dolomite (as D1), with interbedded iron formation, diopsidic dolomite and minor quartzite
- **LIF** Lower Iron Formation, cherty hematite (earthy to specular) and dolomitic iron formation with dolomite interbeds
- **D1** Dolomite, massive to well bedded, chocolate brown weathered, crystalline, often having clastic textures, minor diopsidic sections and iron formation
- **Q1** Quartzite, white, buff and green, granular, massive to well bedded, with minor conglomerate and metapelite
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SYMBOLS

- Area of outcrop
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- A—A' Line of stratigraphic section
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- B309-B315 Samples listed in Table 10
- Mineral occurrence
- U Uranium
- Cu Copper
- Ni-Co Nickel-cobalt
- Au Gold

B242-B248

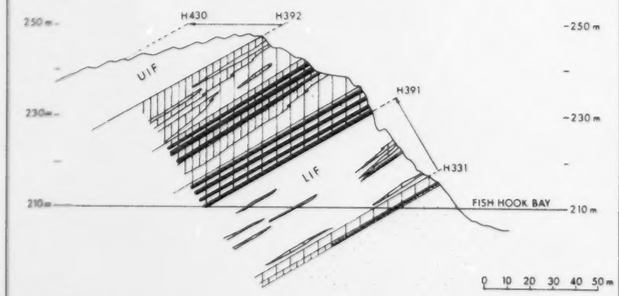
B260-B307

B318-B325

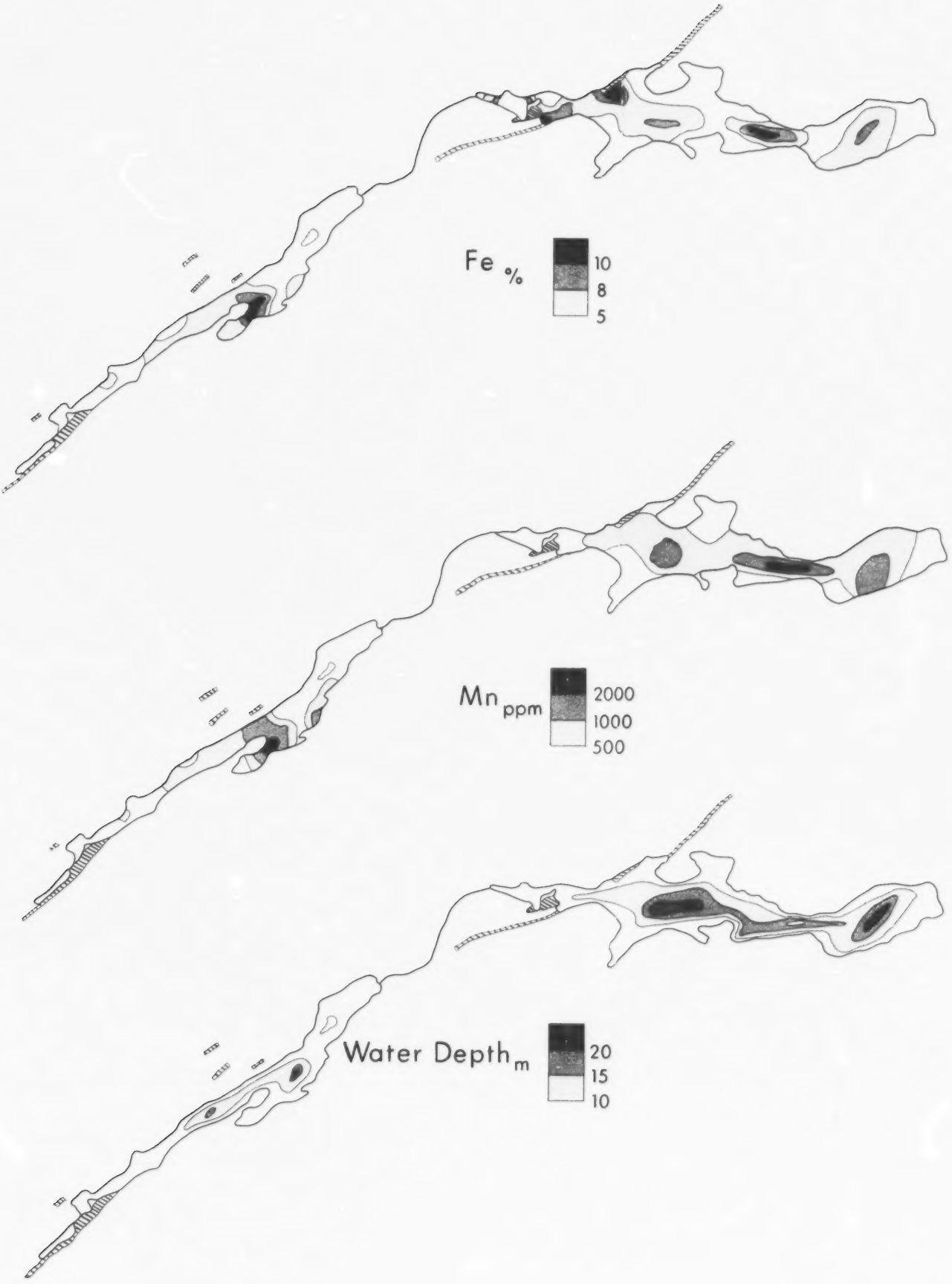
B309-B315 U, Au

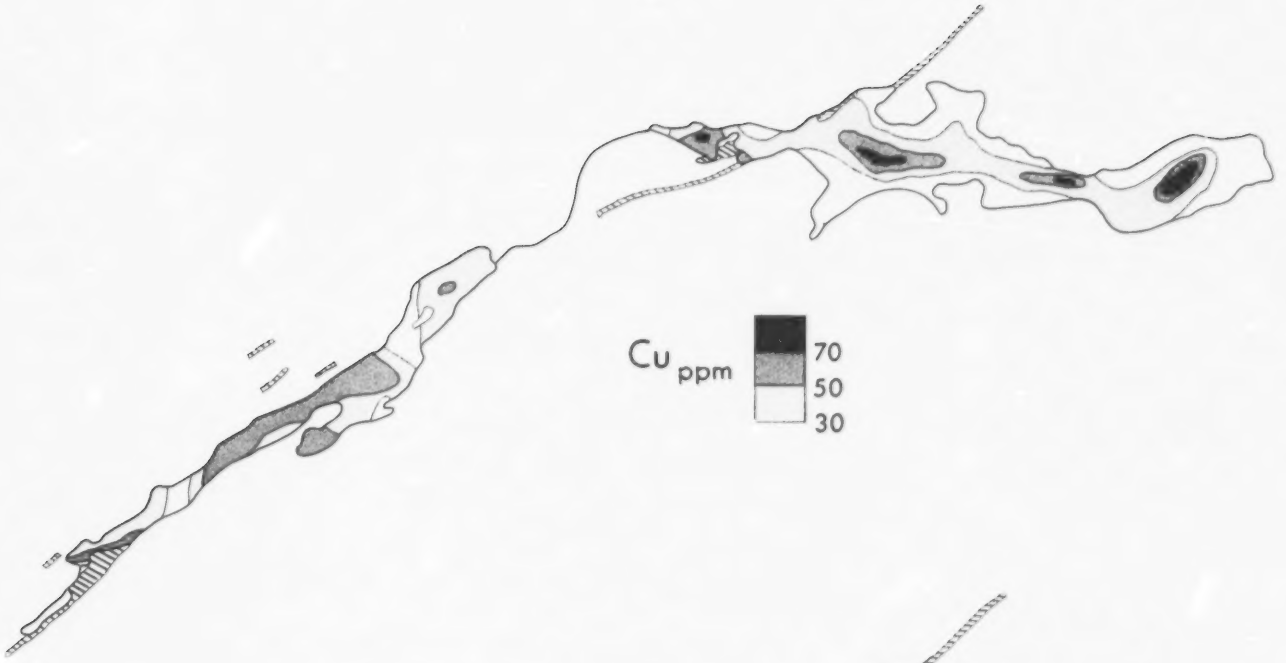
U, Cu, Ni-Co

PART OF SECTION C—C'



UIF UPPER IRON FORMATION
DIOPSIDIC DOLOMITE
DOLOMITE
BANDED IRON FORMATION
LIF LOWER IRON FORMATION
QUARTZITE


Fe %
10
8
5
Mn ppm
2000
1000
500
Water Depth m
20
15
10
0 500 1000 1500 2000 2500 m


Cu ppm
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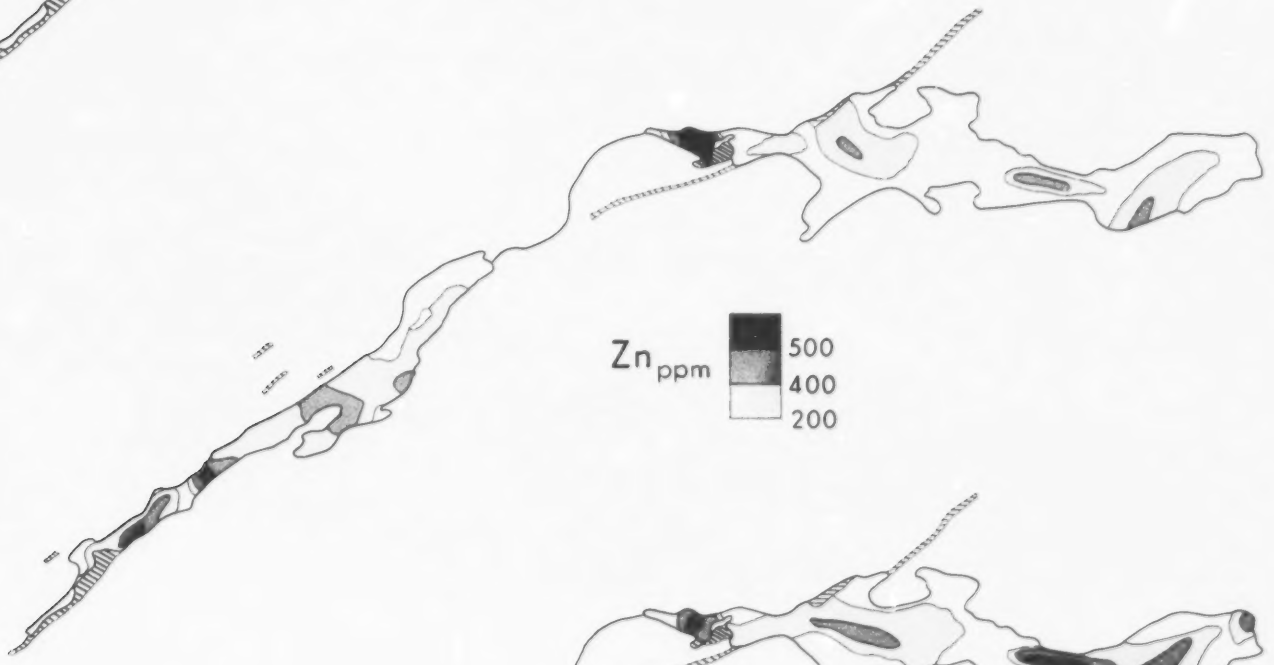
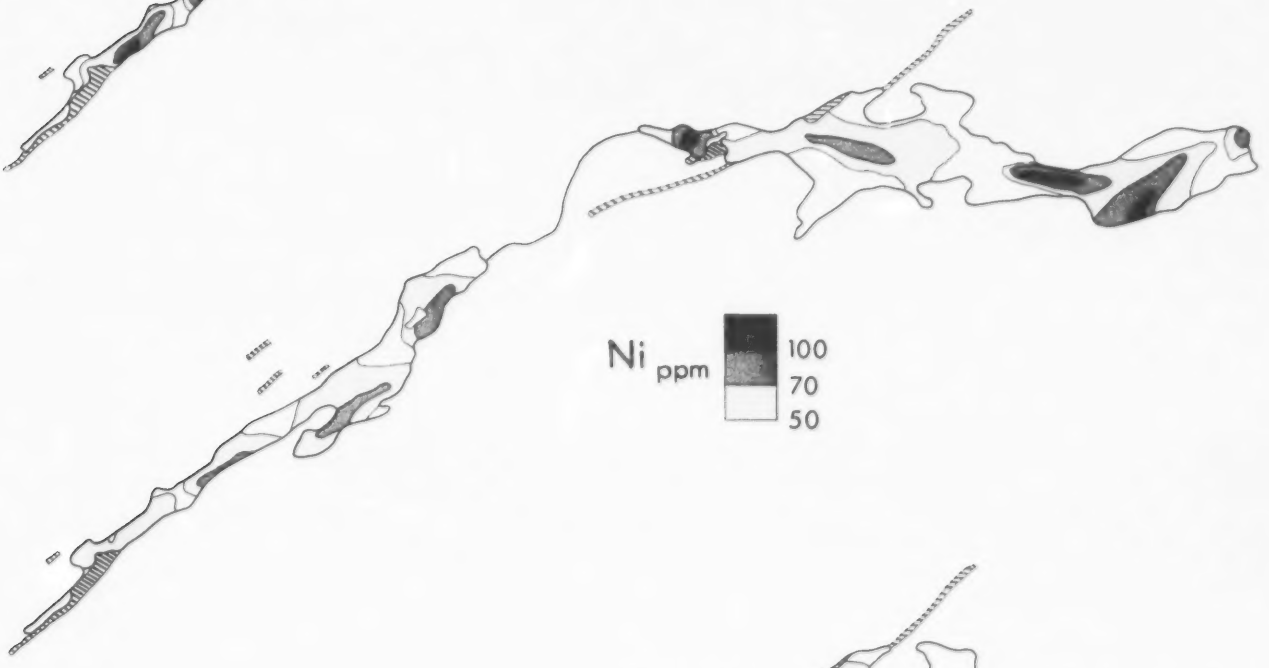
50
30


Zn ppm
500
400
200


Ni ppm
100
70
50

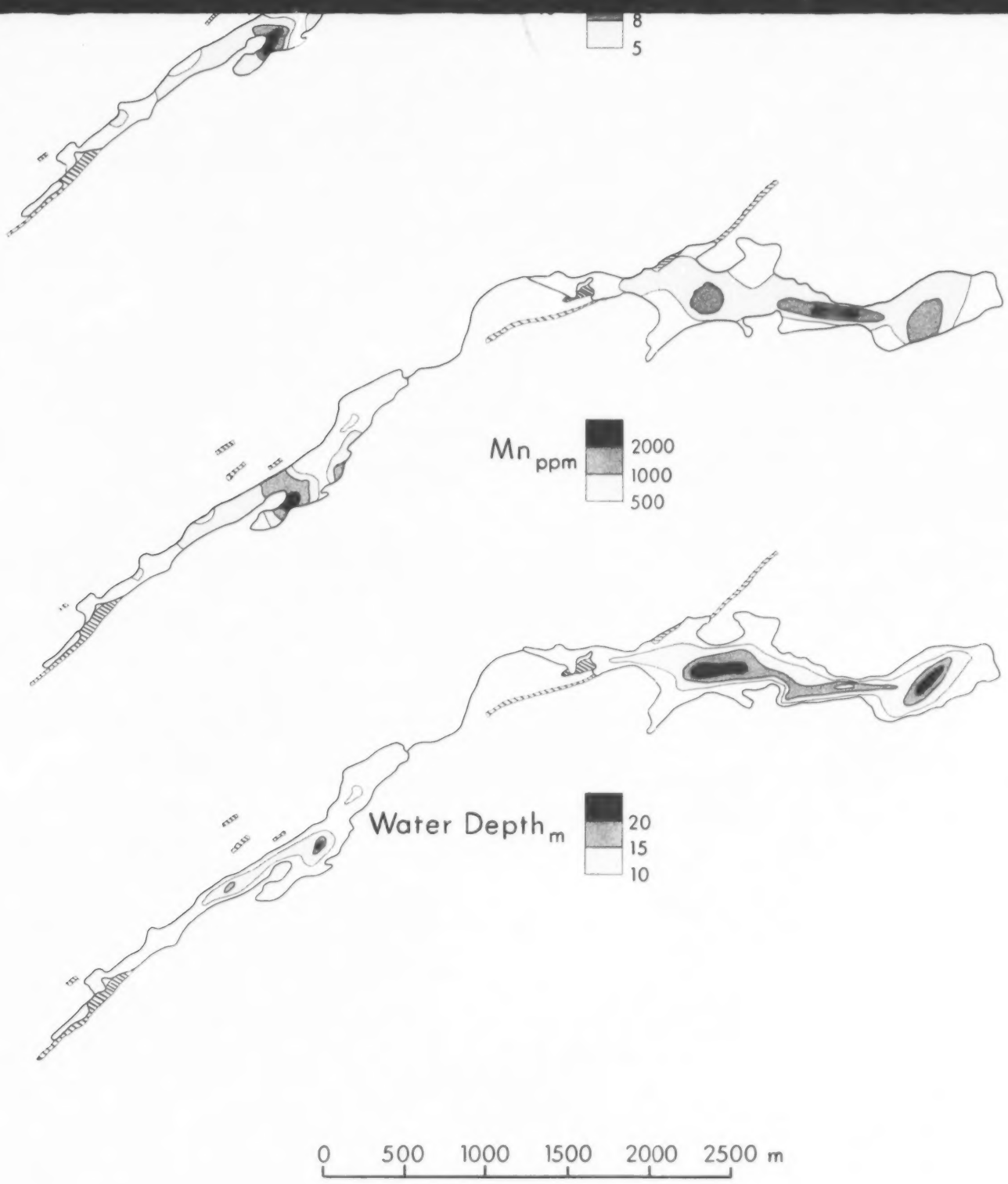
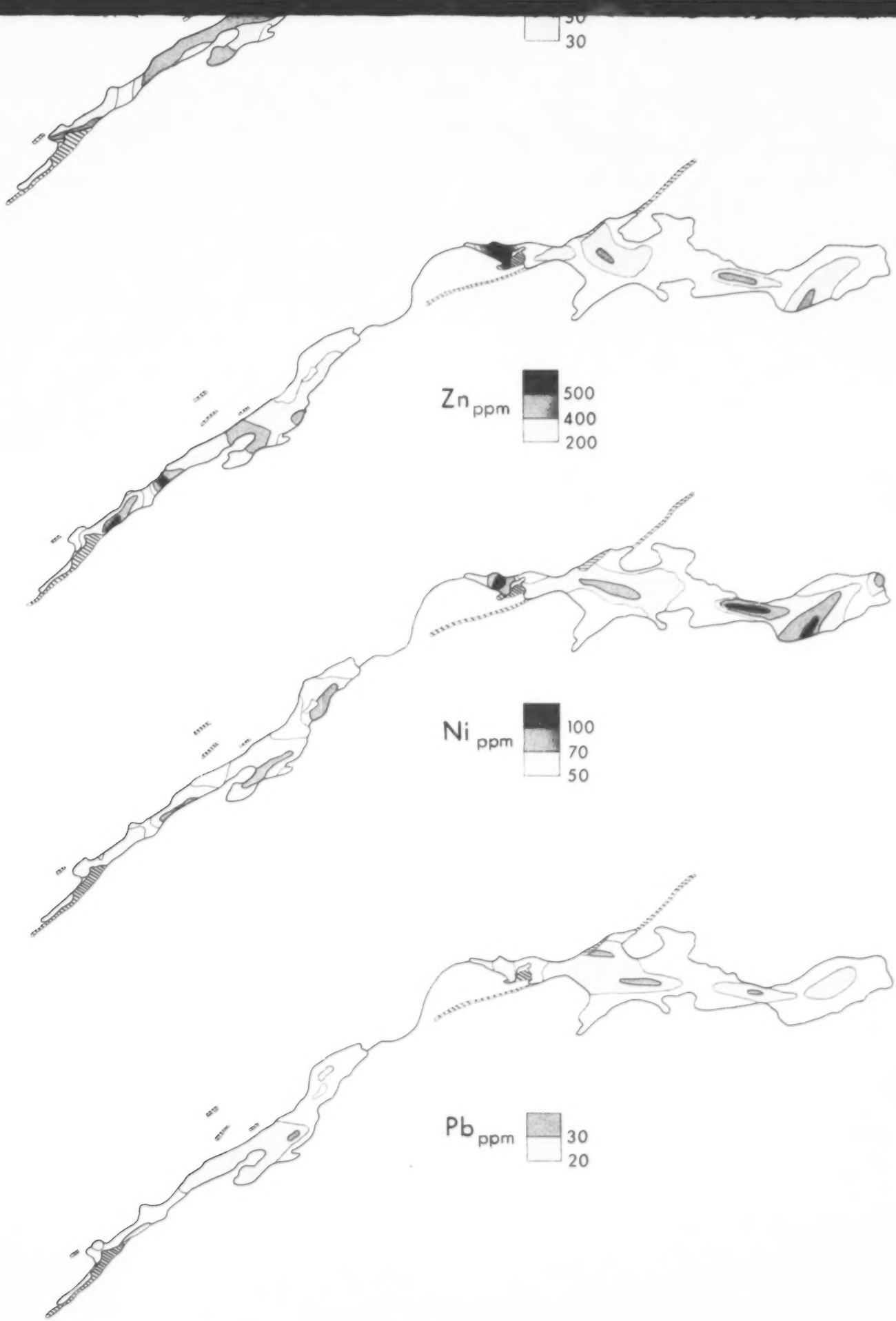


Figure 27. *Lake sediment geochemical results from Gossan and Narrow Lakes. Compiled from field work by Ray (1974).*


30
Zn ppm
500
400
200
Ni ppm
100
70
50
Pb ppm
30
20